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Editor:
J. O. S. MACDONALD, B.Sc., M.I.Chem.E., A.R.I.C.

Associate Editor:
I. BERKOVITCH, Ph.D., F.R.I.C., A.M.I.Chem.E.

Assistant Editor:
DAVID V. MARTIN, B.Sc.

The front cover shows two methane storage tanks at Canvey, each of 1000 tons capacity. The liquid, which is stored at −260°F, is pumped to and from the tanks through insulated aluminium pipelines of 6-12 in. in diameter. Methane can be transferred at 100,000 gph in this system. (By courtesy of the North Thames Gas Board.)

Classified Advertisements, after page 686

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Résumés

B.C.E., 5, 10. 690. U.D.C. No. 658.28:66.073.2.

LA MANUTENTION ET LA DISTRIBUTION DES GAZ LIQUÉFIÉS

par T. J. Webster

L'auteur décrit un certain nombre de dispositions pour la distribution de gaz liquéfiés, l'oxygène, en particulier. Il démontre qu'un système de distribution intégré demande plusieurs opérations : pressurisation des cuves contenant les gaz liquéfiés, transfert du liquide et évaporation. Il mentionne les importants effets de stratification.

B.C.E., 5, 10. 699. U.D.C. No. 536.75:661.937.

L'ENTROPIE : UNE CONCEPTION THERMODYNAMIQUE ET SES APPLICATIONS

par W. Strauss

Une simple réexposition portant sur les deux genres d'accroissement d'entropie qu'un système peut subir : il peut être dû à des modifications à l'intérieur du système lui-même ou à des changements provoqués par l'interaction du système et de son milieu. L'article illustre l'application de cette conception et du principe de l'irréversibilité pour évaluer les cycles réfrigérants.

B.C.E., 5, 10. 703. U.D.C. No. 66.096.5.

QUELQUES CORRÉLATIONS POUR LES LITS FLUIDISÉS À PHASE DENSE

par Max Leva.

L'auteur examine des corrélations se rapportant à la mécanique de l'état fluidisé à phase dense ; elles permettent de prédire le début de la fluidisation et l'expansion du lit. Il illustre l'application de ces corrélations au moyen d'un exemple réel dans lequel la hauteur du récipient à lit fluide est déterminé.

Il considère, également, les déviations d'élutriation de l'équation de Carman et offre une explication dans ce dernier cas.

DÉTECTION RADIOACTIVE DES PERTES EN PHÉNOL DANS LE RAFFINAGE DU PÉTROLE

par R. E. Pegg, M. F. Hoare, J. L. Beton, G. B. Cook et H. E. Dobbs

Un compte-rendu de recherches entreprises à la raffinerie de Fawley pour détecter les pertes en phénol dans une installation de traitement d'huile de graissage. Ces travaux, dans lesquels les chercheurs ont utilisé un élément radioactif, l' o-bromphénol marqué au Br^{82}, pour suivre le sort du phénol, ont montré que les pertes observées ne sont pas dues à des contre-courants de phénol dans l'installation, mais à d'autres causes expliquables, comme la réaction avec d'autres matériaux qui se trouvent dans l'appareillage.

B.C.E., 5, 10. 714. U.D.C. No. 532.542:681.121.8 66.026

LE COEFFICIENT D'ÉCOULEMENT AUX CONSTRICTIONS TUBULAIRES—1e PARTIE

par T. H. Redding

Grâce au traitement unidimensionnel étendu de l'écoulement à travers un rétrécissement tubulaire, l'auteur a pu établir une formule donnant le coefficient d'écoulement qui tient compte de la courbure des courants. Il utilise cette formule pour expliquer le caractère du coefficient d'écoulement pour diverses constrictions servant aux mesures. L'auteur incorpore des facteurs de correction pour tenir compte des effets des facteurs qui déterminent la forme de l'écoulement.

PLATEAUX A PERFORATIONS POUR COLONNES DE DISTILLATION

par Bohuslav Melichar

L'auteur présente des données sur les dimensions des plateaux à perforations comme le diamètre des tubes descendants, l'intervalle entre les tubes, l'espace libre fourni par les perforations. Il souligne les avantages et les inconvénients de ce genre de plateau. Il donne, ensuite, des formules simples pour le calcul approximatif de la capacité des colonnes à plateaux perforés de distillerie et il décrit un nouveau type de plateau à perforations.

Kurzreferate

B.C.E., 5, 10. 690. U.D.C. No. 658.28:66.073.2.

DIE HANDHABUNG UND VERTEILUNG VON VERFLÜSSIGTEN GASEN

von T. J. Webster

Der Verfasser bespricht eine Anzahl von Schemen zur Verteilung von verflüssigten Gasen, und insbesondere von Sauerstoff. Er zeigt, dass ein integriertes Verteilersystem eine Anzahl von Teilverfahren umfasst, darunter das unter Druck setzen von Gefässen mit verflüssigten Gasen, das Umfüllen der Gase und ihre Verdampfung. Das wichtige Problem der Schichtung wird ebenfalls besprochen.

B.C.E., 5, 10. 699. U.D.C. No. 536.75:661.937.

ENTHROPIE—EIN THERMODYNAMISCHES KONZEPT UND SEINE ANWENDUNGEN

von W. Strauss

Eine einfache Zusammenfassung, die sich mit den beiden Arten von Enthropiezuwachs befasst, welchen ein System entweder durch innere Änderungen innerhalb dieses Systems, oder durch Wechselwirkungen dieses Systems mit seiner Umgebung unterworfen werden kann. Der Artikel illustriert dieses Konzept zusammen mit dem der Irreversibilität bei der Beurteilung von Kühlungszyklen.

B.C.E., 5, 10. 703. U.D.C. No. 66.096.5.

WECHSELBEZÜGE FÜR DICHTE WIRBELSCHICHTEN

von Max Leva

Der Artikel bespricht die die Mechanik von dichten Wirbelschichten betreffenden Wechselbezüge, welche die Vorhersage des Beginns der Fluidisierung und der Schichtenexpansion gestattet. Der Einsatz dieser Korrelationen wird anhand eines Beispiels illustriert, in welchem die Höhe eines Wirbelschichtgefässes berechnet wird.

Schlämmungsabweichungen von der Carman'schen Gleichung werden ebenfalls besprochen und eine Erklärung hierfür vorgeschlagen.

RADIOAKTIVE INDIKATOREN VON PHENOLVERLUSTEN BEI DER ÖLRAFFINIERUNG

von R. E. Pegg, M. F. Hoare, J. L. Beton, G. B. Cook, und H. E. Dobbs

Eine in der Fawley-Raffinerie durchgeführte Untersuchung über Phenolverluste in einer Anlage zur Behandlung von Schmierölen. Die Arbeit wurde mittels radioaktiver Indikatoren, o-Bromphenol mit Br^{82}-Markierung durchgeführt und führte zum Schluss, dass die beobachteten Verluste nicht auf Phenolstösse im Aggregat zurückzuführen waren, sondern auf andere, nachweisbare Ursachen, darunter auch die Reaktion mit anderen im Aggregat vorhandenen Stoffen.

B.C.E., 5, 10. 714. U.D.C. No. 532.542:681.121.8 66.026

DER FEHLERKOEFFIZIENT IN ROHREINENGUNGEN — TEIL II

von T. H. Redding

Eine erweiterte eindimensionale Behandlung des Fehlers einer Rohreinengung führt zu einer Formel für den Fehlerkoeffizienten, der die Kurvatur der Stromlinien in Betracht zieht. Die Formel wird dazu benützt, den Charakter des Fehlerkoeffizienten für verschiedene Konstriktionen zu erklären. Korrekturfaktoren ermöglichen die Inbetrachtziehung von Faktoren, welche den Fehler charakterisieren.

SIEBBLECHE FÜR BRENNEREISÄULEN

von Bohuslav Melichar

Daten über die Abmessungen von Siebblechen, wie die Querschnitte von Fallrohren, die Abstände, die durch die Lochung geschaffenen freien Flächen, werden gegeben und die Vor- und Nachteile dieser Art von Blechen besprochen. Einfache Formeln zur annähernden Berechnung der Kapazität von Siebblechsäulen für Brennereien werden angeführt und ein neuer Siebblechtyp wird besprochen.

Резюме

B.C.E., 5, 10. 690. U.D.C. No. 658.28:66.073.2.

ПЕРЕМЕЩЕНИЕ И РАСПРЕДЕЛЕНИЕ СЖИЖЕННЫХ ГАЗОВ

Т. В. Уэбстер

Автор описывает ряд систем распределения жидких газов и особенно кислорода. Он показывает, что интегрированное расположение включает серию отдельных рабочих единиц, осуществляющих такие операции, как создание давления вокруг баллонов с газом, разгрузку газа в жидком состоянии и его испарение. Упоминается важная проблема последствий слоистости.

B.C.E., 5, 10. 699. U.D.C. No. 536.75:661.937.

ЭНТРОПИЯ: ТЕРМОДИНАМИЧЕСКАЯ КОНЦЕПЦИЯ И ЕЕ ПРИМЕНЕНИЯ

В. Штраусе

Констатируются две формы энтропического увеличения системы: в силу изменений внутри самой системы и в результате взаимодействия системы с окружающей средой. Даются примеры применения концепции и явления необратимости в оценке охлаждающих циклов.

B.C.E., 5, 10. 703. U.D.C. No. 66.096.5.

НЕКОТОРЫЕ КОРРЕЛЯЦИИ ДЛЯ ФЛЮИДИЗИРОВАННЫХ НАБИВОК ПЛОТНОЙ ФАЗЫ

Макс Лева

Рассматриваются корреляции, касающиеся механики флюидизированного состояния плотной фазы и дающие возможность предопределять наступление флюидизирования и расширения набивки. Применение корреляций иллюстрируется непробованным примером определения высоты сосуда для жидкой набивки.

Элютриационные отклонения от уравнения Кармана также подвергаются рассмотрению, и в последнем случае предлагается соответствующее объяснение.

РАДИОАКТИВНОЕ ТРЕСИРОВАНИЕ ПОТЕРЬ ФЕНОЛА ПРИ ПЕРЕГОНКЕ НЕФТИ

Р. Э. Пегг, М. Ф. Хор, Дж. Л. Битон, Дж. Б. Кук, Г. Э. Доббс

Итоги исследований, проведенных на нефтеочистительном заводе Фоли, над слежением за потерями фенола в установке для обработки смазочных масел. Опыты с радиоактивным тресером — о-бромофенол меченый бромом 82 — привели к заключению, что наблюдающиеся потери были вызваны не расплескиванием фенола в установке, а другими объяснимыми причинами, в частности реакцией с другими материалами, находящимися в установке.

B.C.E., 5, 10. 714. U.D.C. No. 532.542:681.121.8 66.026

КОЭФФИЦИЕНТ ТЕЧЕНИЯ В ТРУБНЫХ СЖАТИЯХ—ЧАСТЬ 2

Т. Г. Реддинг.

Продолжительная едино-пространственная обработка течения через сжатие в трубе позволяет установить формулу коэффициента течения, которая учитывает изгиб линии струи. Эта формула применяется для объяснения вида действительного течения для различных подсчётных сжатий. Вводится исправительные факторы, что-бы дать возможность действия факторам определяющим линию течения.

СЕТЧАТЫЕ ТАРЕЛКИ ДЛЯ ПЕРЕГОННЫХ КОЛОНН

Богуслав Мелиха

Данные о размерах сетчатых тарелок, включая сечение переточных труб, расстояние друг от друга, свободную площадь, образованную перфорацией, налагаются автором вместе с оценкой преимуществ и недостатков тарелок данного типа.

Приводятся простые формулы для приблизительных расчетов емкости перегонных колонн с сетчатыми тарелками, и описывается сетчатая тарелка нового типа.

DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

"Chemistry is not Enough"

TO the philosophically-minded SIR GEORGE THOMSON'S Presidential Address to this year's British Association meeting will be of great interest. Its keynote was explicitly sounded only towards the end of his text. Science, said Sir George, is not merely the control but also the understanding of nature and he was anxious that its two aspects should be held in equal honour. The ideas of science constitute an achievement of which man should be as proud as he is of the material creations due to science-used technology. This needed saying—perhaps particularly to us, so proud of our fast-developing primary technology.

More directly in our mundane line of interest was the Presidential Address to the Chemistry Section by Dr. James Taylor, M.B.E., of I.C.I. His theme, which we partly quote above as our heading, was the increasing scope of scientists' work in industry. Discoveries were only knowledge. *Per se* new ideas and conceptions were not immediately useful. They would only be exploited by technology, and progress is beset by considerable difficulties. The laboratory discovery is only one event, albeit an important one, in a long train which culminates in successful large-scale manufacture. To plagiarise Longfellow.

First the beaker, then the pail,
Then the semi-technical scale,
Next the plant and then disaster,
Swiftly following faster, faster.

The follow up after the initial discovery involved applied research, development and chemical engineering. But the whole project was a complex, orderly process, in which scientific technical, engineering and financial staffs all played essential parts in a combined operation. Adequate scientific data were necessary for its inception and design, efficient technical resources for its construction and sufficient funds for financing it. All these aspects were equally important and, any one, if neglected, could imperil the whole.

Identifying Pipelines

THERE is a growing tendency to adopt British Standard colour-identification for pipelines since this has been found to be helpful in avoiding confusion in operation and maintenance. But because of the large numbers of individual chemicals and the limited number of readily distinguishable colours only services are identified individually by a distinctive ground colour. Other fluids under the general heading "chemicals" are grouped together under a common ground colour. Colour bands are then superimposed upon the ground colour to distinguish one kind or condition of fluid from another kind or condition of the same fluid—as for example, oil for hydraulic power and transformer oil. Hazards are identified as one of three groups. Lightly radio-active hazards are shown by a panel or band having a jasmine yellow ground with black diagonal crossed stripes; heavily radio-active hazards have a panel or band with a light orange ground and black diagonal crossed stripes; while other hazards show a panel or band having equal diagonal stripes of black and golden yellow.

When further means of identification are required to supplement the colour code the Standard* recommends that each industry should agree on the best method suited to its own requirements. This may be done by using lettering and/or suitable colour bands.

This is a current revision of a specification first issued in 1951. The Annual Report for 1959-60 of the British Standards Institution shows a range of items in progress in the field of chemical engineering. They include preparation or revision of standards for pressure vessels, steels, oil burning equipment, metallic finishes and gas cylinders.

* "Identification of Pipelines" B.S. 1710: 1960 6s.

Flow Properties of Sodium

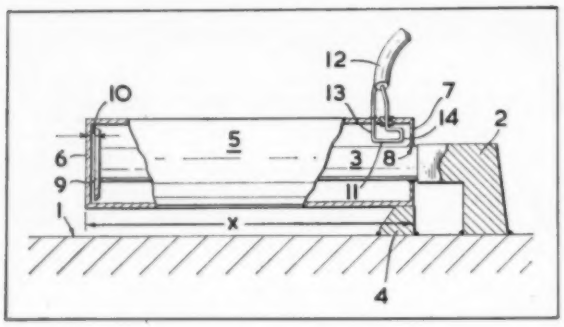
AT low rates of flow of sodium used as a coolant, natural convection circulation loops are set up even in small pools of the liquid because of the high thermal conductivity, high film coefficients and moderate density change with temperature. This peculiarity encountered by workers of U.S. Atomic Energy Commission was thought to provide a large "area of uncertainty" despite the fact that sufficient hydraulic and fluid flow information has been developed to permit routine design of liquid metal heat transfer systems and equipment utilizing forced convection. Since liquid sodium is quite similar to water in its flow characteristics in forced convection new component designs are usually checked experimentally using water. It is then possible to make reasonably accurate prediction of the flow characteristics for sodium.

As part of the development of a sodium cooled, graphite moderated thermal neutron spectrum reactor* with a low pressure heat removal system, fluid flow experiments are now being undertaken on a mockup of the calandria core, which will be operated first with water, and later with sodium. The objectives are to determine flow and temperature distribution patterns around the core and to determine its response to temperature transients. The electrically heated mockup will be about $\frac{1}{4}$-scale of a proposed experimental reactor (SCRE); it is hoped that it will prove possible to correlate data by dimensionless parameters to the reactor experiment.

* Civilian Power Reactor Program Part III, Status Report on Sodium Graphite Reactors as of 1959, TID-8518(6) 1960 Atomic Energy Commission. Price $1.00.

Strain Gauges for Higher Temperatures

AT normal atmospheric temperatures strain gauges have been extensively used for checking the performance of a variety of stressed structures. The Atomic Energy Authority has now announced a device of this type for use at "high temperatures." It may be recalled that the rising interest in this field—particularly for applications in aircraft and nuclear research—led to the holding of a



Symposium by the Aeronautical Structures Laboratory of the U.S. Naval Air Material Center.* At that meeting assessments were presented of very specialised instruments usable at temperatures up to 1200°F. The extensometer now developed by the Authority's electrical engineers at Risley—intended for testing of pressure vessels in inaccessible positions—has been successfully used on a plant with an outlet temperature of 340°C. This instrument is claimed to be robust yet sensitive, to have good temperature stability and wide range, although no figures have been given for these properties. As shown in the diagram the gauge consists of a bracket (2) welded to the pressure vessel (1) carrying a solid conducting rod (3) parallel to the vessel's surface. Close to the bracket, a lug (4) is also welded to the pressure vessel and carries a hollow cylindrical conductor (5) parallel to the vessel and surrounding the rod. One end of the hollow cylinder is closed by an integral wall (6) and the other by a diaphragm (7). The end of the rod carries a conducting disc (9) spaced slightly from the cylinder end-wall to provide an air-gap (10). A coupling loop (11) from a feeder (12) lies between the conducting rod and cylinder. One arm (13) of the loop is in contact with the cylinder wall and the other (14) is insulated from it. A conventional variable frequency oscillator is connected to the feeder.

Change in the surface strain causes variation in the capacity of the condenser formed by the end-wall (6) of the cylinder and the disc (9) on the rod. The change of characteristics shown as a change of wavelength, is then measured by the oscillator. Further information is available from the Patents Exploitation Officer of the Authority.

* "Symposium on Elevated Temperature Strain Gages." American Society for Testing Materials Special Technical Publication No. 230 1958 $4.50.

What Prospects for Coal?

IN the course of preparing their recommendations for research and development on coal-based processes, the Wilson Committee have also produced a valuable survey of the often under-rated chemicals-from-coal industry—which has an annual output of a million tons of organic chemicals, 600,000 tons of ammonia and 150,000 tons of other inorganic chemicals. What are the major conclusions?

Carbonisation will continue to be the most important method of processing coal in this country and town gas offers the greatest scope for expansion. However, to make this possible, new plants will have to make gas more cheaply than existing ones. The committee point out* that the Lurgi process is the most promising method available now for basing such an expansion on coal. But gas made by this process must be enriched before it is suitable for use as town gas and there is at present no commercial process for making rich gas direct from coal. Petroleum products can be used economically to enrich the lean gas made in Lurgi gasifiers, and in this way coal and oil are complementary. Development of high pressure slagging gasifiers may make possible improvements in the technique of gasifying coal which in turn would result in a significant reduction in the cost of gasifying coal.

Though it is little more than a year since the pilot plant for Fischer-Tropsch work was re-set up at the Warren Spring Laboratory, fresh appraisal of the prospects for making oil from coal economically in this country has led to depressing conclusions. When the work at present in hand has been completed no further technological work specifically directed towards the oil-from-coal process should be undertaken. Yet since the major part of the cost of the complete process is accounted for by the cost of making synthesis gas, the economics of making oil from coal should be reviewed whenever there is a substantial advance in coal gasification and work on basic studies should be intensified. Novel to Britain is the further suggestion that if the cost of making lean gas from coal can be reduced sufficiently, there might be a substantial industrial market for it without enrichment, using a separate industrial gas grid. What have been the reactions? We understand that the Minister has asked the nationally-owned fuel industries to avoid public comment but there is known to be some disappointment in the coal industry about the final conclusions. There is, for example, no suggestion for co-ordinating and directing fuel research policy as an integrated whole.

Is there to be no permanent body to continue to review this field and make recommendations to the Minister? Must we wait for further coal crises to provoke the appointment of another special committee? And if it is argued that the Scientific Advisory Committee to the Minister of Power has this function of continuous review, why was it necessary to set up the Wilson Committee?

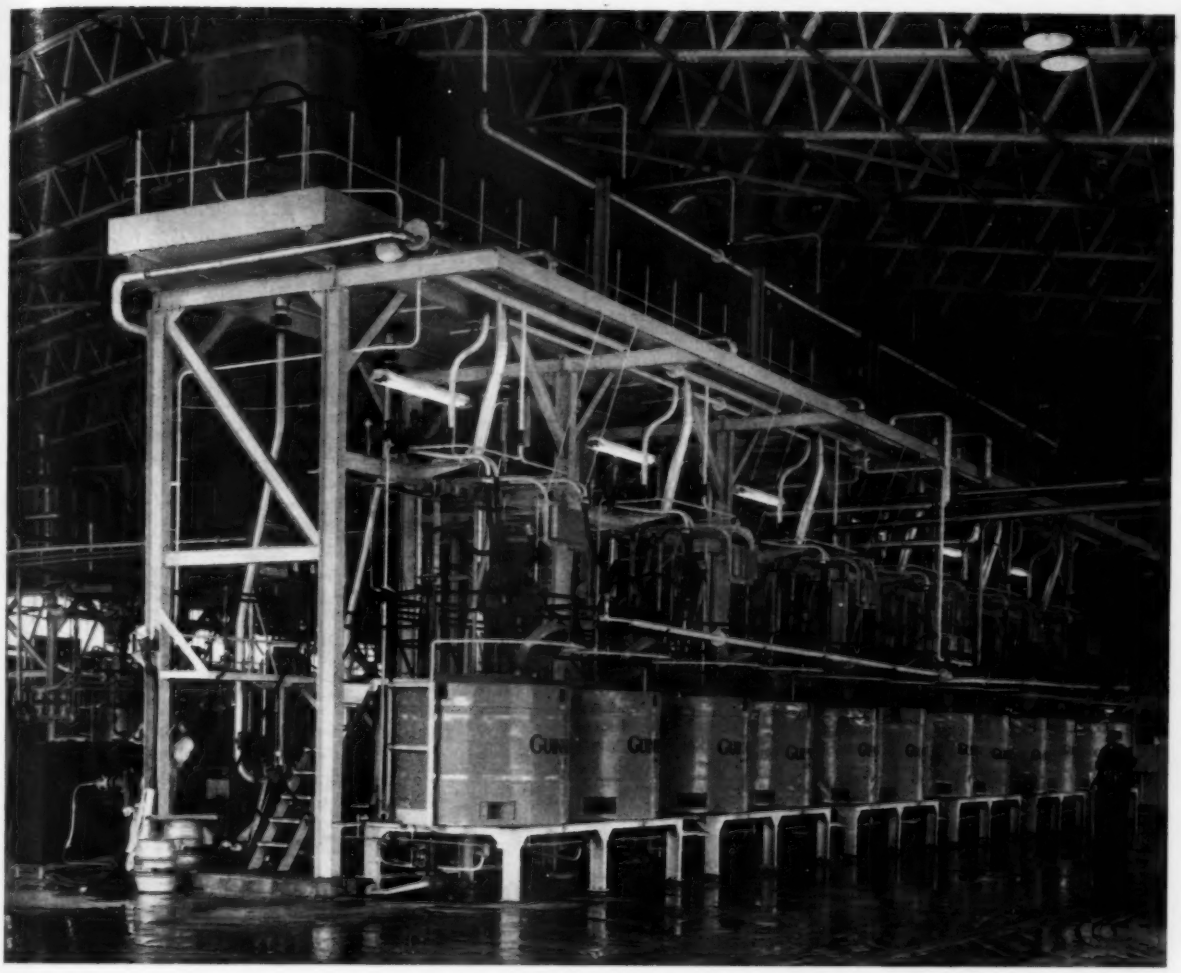
* Report of the Committee on Coal Derivatives. Cmnd.1120 H.M.S.O. 4s.

Training the Non-Apprentice

THE majority of boys who at present enter industry and do not receive training as formal apprentices receive no systematic training at all. The Industrial Training Council has now published a booklet surveying the principles of training for the non-apprentice and citing examples of schemes at a number of named firms. The Council has reached the firm conclusion that systematic training is essential for *all* boys entering industry in whatever capacity they are immediately employed. Essential elements are planned practical training in the workplace and further education. In the booklet attention is again drawn to the truism that the increasingly rapid pace of change in industrial techniques and processes, is constantly demanding an ever higher degree of adaptability on the part of industry's work people. This is indeed the major reason why engineers as well as formal industrial supervisors would do well to give the proposals their attention.

There is of course a general social need for further education but the Council—which had the support of the Association of Chemical and Allied Employers—concluded* that industry itself would benefit by extending day release facilities, or their equivalent, for further education ot all boys up to the age of 18.

* "Training Boys in Industry - the Non-Apprentice" Industrial Training Council, 36, Smith Square, London, S.W.1. 1960. 1s. 9d.



Guinness is good for you . . .

And its goodness is safeguarded by the scrupulous cleanliness of the transportable tanks in which it is exported from Dublin, to be enjoyed in all parts of the world.

At the "tank station" shown above each of these 500-gallon stainless steel or aluminium containers is subjected to very thorough washing and sterilising processes before filling — the whole cycle of operations being regulated through G. A. Platon Control Panels designed and manufactured to satisfy the exacting Guinness requirements.

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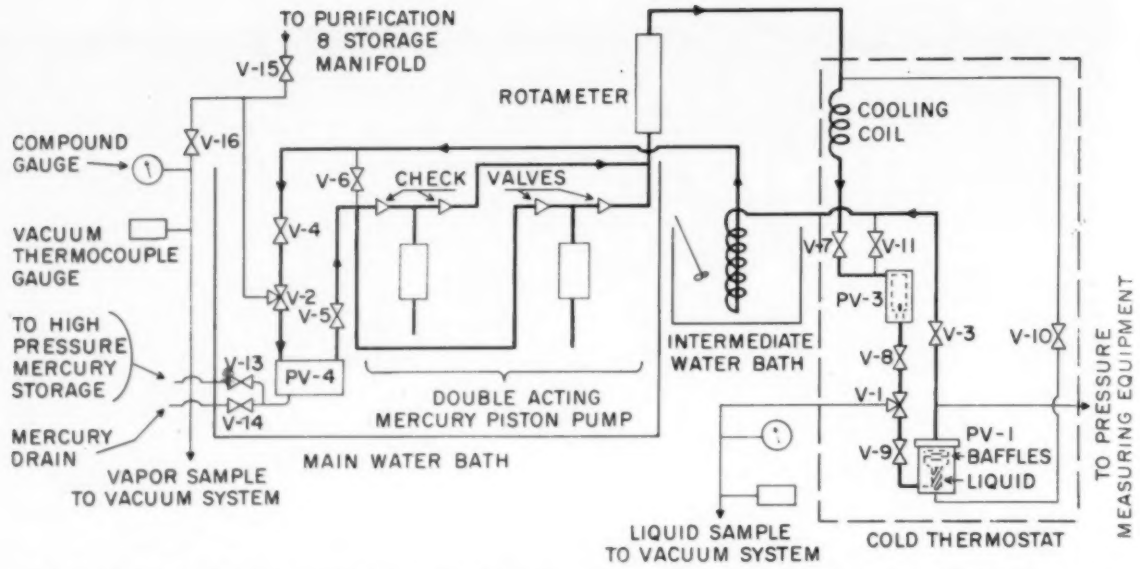

Reproduction of Simplified Flow Diagram of Recirculation Equipment for Liquid Vapour Equilibrium Studies.

Properties of Ammonia

TABLES of critically-assessed values for the properties of ammonia have been published by Vukalovich *et al* of the Moscow Power Institute*. The study leading to their issue was prompted by the extensive use now being made of ammonia as a heat-transfer medium. Figures for pressure, volume and temperature cover the range 40 — 290°C., those of specific heat at constant pressure are for the range 40 — 280°C. and the viscosity tables 30 — 250°C. Pressure range in all cases is 1 — 800 kg/cm². Although values of the specific volume of ammonia are given for temperatures up to 290°C., those available for higher temperatures were not used because of the evidence of decomposition. The values tabulated were obtained by calculation and graphical methods. There is satisfactory agreement with other authors and differences do not exceed 0.2 — 0.3%. Work done on specific heat at constant pressure was also reviewed by Dr. Vukalovich. Again values were calculated or determined graphically and the results plotted. It was considered that the errors in this table may be 2 — 3%, and on the 150°C. isotherm at pressures of 100 — 150 kg/cm² they may be somewhat greater. The properties of ammonia on the saturation line have been studied by several authors but the data were thought to be inadequate; the thermo-dynamic properties of ammonia on the saturation line from temperatures of — 70 to + 132.4°C., have therefore also been presented. It is suggested that figures in the paper for viscosity are accurate and reliable up to 250°C. and 800 kg/cm².

* *Teploenergetika*, 1960, No. 1, p. 63.

Liquid Sampling from Liquid-Vapour Equilibrium Apparatus

AS part of the preparations for a programme of determining liquid-vapour equilibrium in the hydrogen-nitrogen and deuterium-nitrogen systems, Arturo Maimoni of California University developed his own liquid sampling system. The method of operation* can be shown by reference to the accompanying simplified flow diagram of the recirculation equipment. The equipment is filled by opening valve V-15, then the double-acting mercury-piston pump turned on, forcing the gas to circulate along the path indicated by the heavier line in the figure. Meanwhile all the bypass valves, V-6, V-10 and V-11, are closed. The gas passes through a rotameter to the cold thermostat, then through V-7, PV-3, V-8, the liquid-sampling valve V-1, and V-9, and bubbles through the liquid in the equilibrium cell PV-1. Vapour leaves the liquid, goes through a series of baffles inside PV-1, to remove entrained liquid, then through V-3 and outside the cold thermostat to a heating coil. From there it goes back into the main water bath and through V-4, V-2, PV-4, and V-5 back to the inlet of the pumps. Time is allowed for the vapour and liquid phases to come to equilibrium and the bypass valves. V-6, V-10. and V-11, are opened to flush the small amount of gas present in those lines with equilibrium gas. Then the normal circulating path is resumed for another five minutes, the bypass valves again flushed and further time allowed for the system to go back to equilibrium conditions.

For sampling, valves V-11, V-10, and V-6 are opened consecutively. The gas sample is taken by closing valves V-4 and V-5 which isolates the equilibrium vapour in PV-4. To obtain the liquid sample, the liquid-level indicator in PV-3 is turned on and V-7 closed, forcing the gas to circulate through V-10. Then V-3 is partially closed and the pressure drop through it forces the liquid at the bottom of PV-1 into the line leading to PV-3. When the liquid reaches PV-3, valves V-8 and V-9 are closed, trapping about 2 ml of liquid in the line. The liquid sample is sent to the vacuum system for analysis by opening V-1. The valves V-1, V-8, and V-9 were specially designed to minimize the possibility of trapping small bubbles of vapour in the line. This procedure is certainly rather complicated but is thought to be justified since it removes all uncertainties in the composition of the liquid sample.

* Full details are in Report UCRL-5719 University of California, Laurence Radiation Laboratory.

Elmer A. Sperry—Engineer and Chemist

BORN 100 years ago on October 12, Elmer A. Sperry was a versatile inventor who benefited chemical industry as well as engineering—a point sometimes forgotten since his *chef-d'oeuvre* was the Sperry gyroscope used the world over in ships and planes. This descendant of the Sperry family, who emigrated to New Haven, went only part-time to Cornell University; but in its laboratories he decided on his future career when he caught sight

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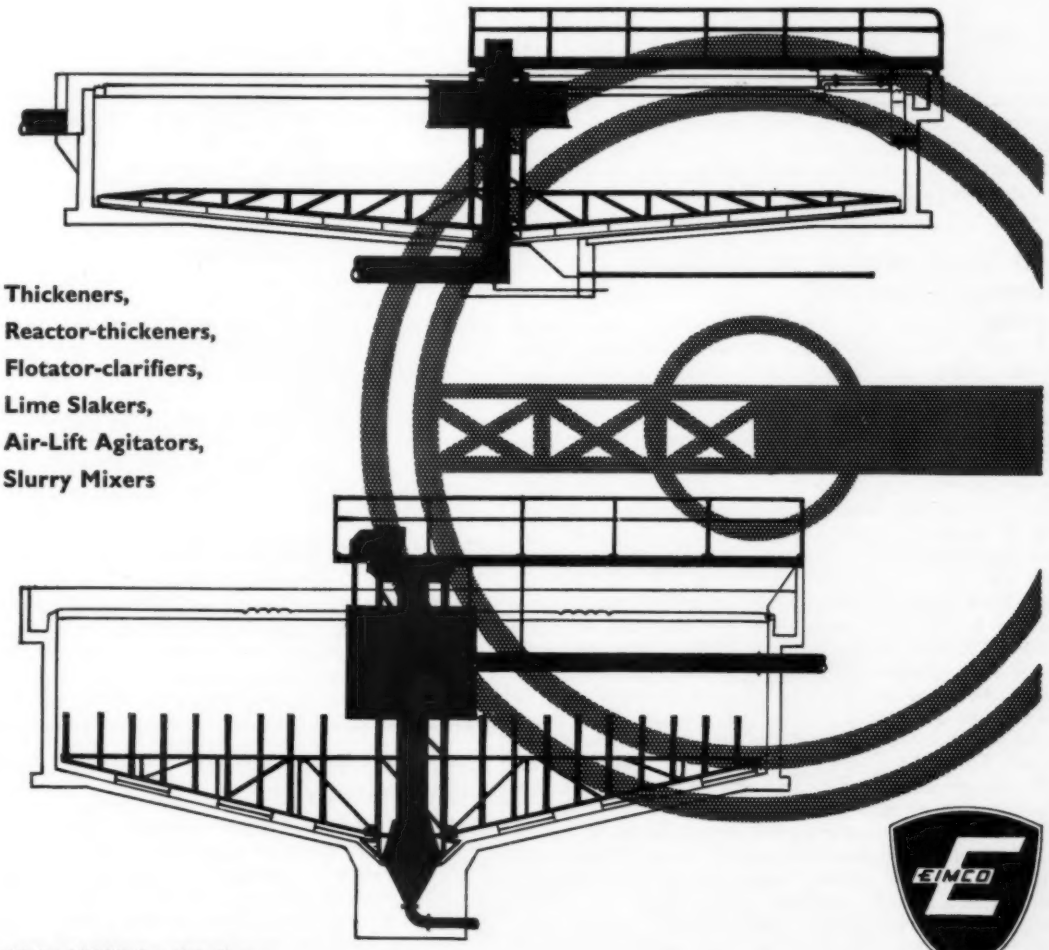

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P.2699

of a first Gramme machine. There followed in the course of time the invention of the Sperry arc lamp and beacon, the founding of companies such as the Sperry Electric Railroad Company, development of electric batteries and of the Sperry searchlights used by most armies and navies. Then, some 60 years ago, Sperry turned to electrochemistry. As assistant in his research laboratory he had C. P. Townsend, a chemist who collaborated in the production of caustic soda and chlorine from salt. So successful was this new venture that the Hooker Electrochemical Company joined in it with a large-scale plant at Niagara Falls. Though the original diaphragm of Sperry and Townsend was later modified, the activities of this company with Leo Baekeland of Bakelite fame as a consultant is well outlined in the Transactions of the American Institute of Chemical Engineers in 1920. Later the chlorine by-product was applied in detinning scrap cans. Goldschmidt had used pressure to force chlorine into corners of such scrap in his detinning, while others like Acker tried liquid chlorine to ensure contact. But Sperry had the inspiration to use liquid stannic chloride as medium between the scrap and chlorine gas, his many patents being adopted by the Goldschmidt Detinning Company. Still another contribution in the chemical field was the process for white lead production, operated at Chicago by the International Lead Company. While the engineering world will be commemorating his many inventions, chemical industry can also claim some part in noting this centenary.

Will Thick Welded Piping Stand Pulsating Pressures?

HIGH pressure pipe systems of relatively small bore are customarily constructed using mechanical joints between lengths of piping. These joints represent a considerable proportion of the cost of such a pipe installation, and for this reason the British Welding Research Association has organised an extensive system of stringent fatigue tests on butt welds in thick pipes. In an interim report* on this programme it is said that mild steel specimens tested in the unwelded as-drawn condition sustained 2 x 10^6 applications of a pressure only marginally less than that sustained by Fortiweld and 12/14% chromium steel specimens in the same condition. When the plain pipes were machined, the pressure sustained was roughly doubled for the alloy steel pipes, but was only one-third greater for mild steel specimens. Mild steel specimens which were manually welded, pressure welded or flash welded all failed at locations clear of the weld with no decrease in strength over that of the unwelded pipes. Some decrease in strength was observed in manually welded Fortiweld pipes, which sometimes failed at the weld, but pressure welded specimens failed without exception in the parent pipe.

In service, the pressure loading approximates to a comparatively small fluctuation about the mean working pressure of the system. A further series of tests has therefore been carried out to produce results applicable to the idealised service conditions. The tests were reassuring in showing that, for instance, flash butt welded mild steel specimens sustain at 2 x 10^6 cycles a pressure cycle of an amplitude (no less than $\pm$450 atm) which is almost insensitive to increases of mean pressure to 2,000 atm, (13 tons/sq. in.). Unwelded Fortiweld specimens showed a similar insensitivity to increases in mean pressure. On the other hand, plain specimens of 12/14% chromium steel were strongly affected by increases in mean pressure over the same range, with a performance at 2,000 atm mean pressure actually inferior to that for flash butt welded mild steel.

Some further testing at high mean pressures is planned for flash butt welded Fortiweld specimens and for dressed 12/14% chromium steel pipes to complete the programme, and to establish further the sensitivity of the alloy steels to increases in mean pressure.

* Fifteenth Annual Report 1959-60. British Welding Research Association, Abington, Cambridge.

Survey of Valve Types

THOUGH its primary purpose is to look at valves for use in atomic energy, a recent set of articles in *Nuclear Power** on valve types and uses will be of wider interest. Opening with a review by D. IGGULDEN of engineering problems common to all valves, it includes a discussion of the new difficulties in designing gas valves for nuclear power stations and a buyers' guide. In an article on corrosion-resisting valves H. E. THRELFALL notes that for economy a more resistant material may be used for the valve trim (seat, disc and stem) and a less expensive material for the main body parts where there is more tolerance for corrosion before failure. This is commonly the case in cast iron or cast steel valves. But when stainless steels and special alloys are used there tend to be more pitfalls for the unwary. One major difficulty is crevice corrosion—a descriptive term to describe a process leading to extremely high rates of corrosion only in the crevice area whilst the rest of the material is virtually unaffected. Another is the possibility of electrolytic (or galvanic) corrosion taking place between the two materials used.

There is a third problem which sometimes arises in the use of trimmed valves and when the pipes and valves are of different metallic materials. This is due to corrosion of one material by the corrosion products from the other, when these products are soluble in the liquid being handled. It is not possible to lay down any simple rules for avoiding this problem and the only suggestion is to consider the various materials in the system, the likely corrosion products resulting and their possible effects on any part. When such corrosion does occur it may be confused with electrolytic corrosion because of the preferential nature of the attack.

* 1960, Vol. 5, No. 53.

Continuous Solvent Degreasing of Wool

RAW wool contains lanolin secreted from the skin of the sheep mixed with sand, dirt, and other impurities. Usually the wool is cleaned by washing in warm, alkaline soap solutions in large vats or bowls. The scouring liquor inevitably causes some damage to the wool and the mechanical agitation used brings about felting and entangle-

Fresh Drive Against Effluents from Leather-making

THE British Leather Manufacturers' Research Association is appointing two new liaison officers—one a specialist in vegetable tanning, the other in chrome tanning—to recommend and demonstrate to supporting firms modifications in leather making processes designed to reduce effluent problems. A mobile laboratory will be equipped to undertake the analytical tests required in this work and sent round with an analyst-demonstrator to instruct tannery staff in the analytical techniques needed to examine trade effluent.

The scheme is an extension of the normal work of the Association, made possible by the provision of additional funds from the industries concerned and D.S.I.R.

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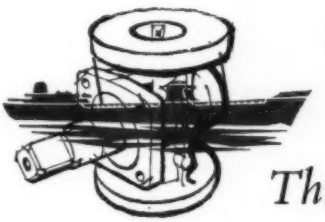

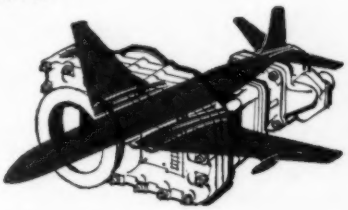

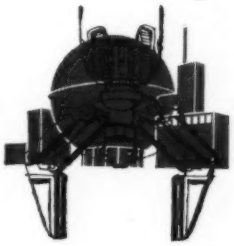

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Institution of Chemical Engineers Graduates & Students Section Annual Dinner & Dance

THIS year the Dinner and Dance will be held on the excellent premises of the Royal Overseas League in St. James', on Thursday, October 20th.

In previous years this function, which is held during the period of the Section's Annual Symposium, has been held on a Friday evening.

This year, by holding the Dinner and Dance on a Thursday evening, it is hoped that those members and visitors who have travelled to London for the Symposium and are therefore staying overnight, will be able to come along.

Among its guests the Section has invited a number of distinguished visitors with their ladies, and the guest of honour is Professor R. S. Edwards. Deputy Chairman of the Electricity Council, and Professor of Economics with special reference to Industrial Organisation in the University of London.

As in former years, the occasion will be semi-formal, and dinner-jackets or dark lounge suits should be worn. The price of the tickets will be 27s. 6d. per head; a bar will be available, and dancing will continue until midnight.

ment of the fibres, resulting in breakage during later processing. There have been numerous attempts to develop a practical solvent-degreasing process using solvents that do not damage the wool. Most of these have been batch processes and have included a soap-scouring stage to remove dirt. However, a project by the Australian Commonwealth Scientific and Industrial Research Organisation has now resulted in the installation of a commercial continuous plant in Hindmarsh, South Australia, based on development work by Mr. J. F. Sinclair.

Wool is carried on a wire mesh conveyor—trials are also being carried out on the use of perforated drums—under jets of a petroleum white spirit solvent. This dissolves the lanolin and the force of the jets removes much of the dirt, with little disturbance of the wool. Excess solvent is removed by squeeze rollers, and the wool then passes under jets of water which removes more dirt and other impurities. The water also displaces residual solvent in the wool which then passes through a second set of squeeze rollers to the drier. The dirt is separated from the solvent which is later distilled for re-use. Pilot plant trials on more than 20,000 lb. of wool showed that the wool was much whiter than with soap scouring, fewer fibres were broken during processing, and the proportion of top, consisting mainly of long fibres, to noil, mainly short fibres, was higher. More than 70 per cent of the lanolin in the wool could be recovered in marketable form.

DIARY

Institution of Chemical Engineers

October 5. *Midlands Centre.* In Department of Chemical Engineering, University, Birmingham, 15, 7 p.m.
"Companies Finance" by K. A. Ward.

October 6. *East Midlands Centre.* In Loughborough College of Technology, 7.30 p.m. Annual general meeting and technical film show.

October 10. At the Royal Institution, London, W.1, 3 p.m. Symposium on surface effects and liquid behaviour.

October 12. *Midlands Branch.* At Midland Hotel, Birmingham, 6.30 p.m.
"Fundamental considerations in biological treatment of effluents" by A. L. Downing and A. B. Wheatland.

October 25. *North Western Branch.* At The Manchester College of Science and Technology, 6.30 p.m.
"Computors and their application in chemical engineering" by D. W. Holman and J. J. Settle.

European Federation of Chemical Engineering

October 24-25. At Barcelona. Twenty-ninth meeting. Journées de genie chimique in conjunction with the thirty-second International Congress of Industrial Chemistry.

National Engineering Laboratory, East Kilbride, Glasgow

September 27-30. Symposium on Flow Measurement in Closed Conduits.

Welsh College of Advanced Technology, Cardiff

October 13; November 3. Course on "The Chemistry of Some Plastic Materials."

South-West Essex Technical College and School of Art, Walthamstow, E.17

September 27 onward. First Course in "Electronic-Chemical Instrumentation."

Exhibitions and Conferences

October 4-12. Second British Electronic Computer Exhibition; and Second Business Computer Symposium at Olympia, London, W.14.

October 18-21. First Effluent and Water Treatment Exhibition and Convention at the Seymour Hall, London, W.1.

October 5-7. 27th Annual Conference of the National Society for Clean Air in Harrogate.

Special Courses

Bulletins of Specialized Courses organized by Regional Councils of Higher Education are obtainable from the following addresses:—

Yorkshire Council for Further Education,
52, Upper Basinghall Street,
Leeds, 1.

London and Home Counties Regional Advisory Council for Higher Technological Education,
Tavistock House South,
Tavistock Square,
London, W.C.1.

West Midlands Advisory Council for Further Education,
161, Corporation Street,
Birmingham 4.

Northern Advisory Council for Further Education,
5, Grosvenor Villas,
Grosvenor Road,
Newcastle upon Tyne, 2.

East Anglian Regional Advisory Council for Further Education,
Stracey Road,
Norwich,
Norfolk.

Regional Advisory Council for the Organisation of Further Education in the East Midlands,
12, King John's Chambers,
Bridlesmith Gate,
Nottingham.

ADVISORY SERVICE ON INDUSTRIAL EFFLUENT TREATMENT

A DEVELOPMENT of major significance in the topical and vitally important field of industrial effluent treatment and purification was announced today. Simon-Carves Ltd. and Monsanto Chemicals Ltd. have pooled their research, engineering and operating experience in the treatment and harmless disposal of industrial effluent to form the Simon-Carves Monsanto Effluent Advisory Service. The service is administered by Simon-Carves Ltd. from their headquarters at Cheadle Heath, Stockport, Cheshire.

Both at home and overseas this Effluent Advisory Service puts a unique range of facilities at the disposal of industries and public authorities faced with problems of effluent treatment and disposal. The service provides general advice on effluent problems, on-site and laboratory investigations on the treatment of specific effluents, recommendations and design data for effluent treatment processes and plants, and continuing advice on the operation of commissioned treatment plants.

In addition to the advisory service the full engineering and contracting organisation of Simon-Carves Ltd. is available for the actual construction, installation and commissioning of complete effluent treatment plants. This combination of advisory and constructional facilities renders the Advisory Service unique in its field.

This firm, as designers and contractors to the coal carbonising, gas and chemical industries, have had considerable experience of effluent treatment. In particular, they have carried out in recent years, and are still engaged on, intensive laboratory, pilot-plant and field-scale research and development on the treatment of effluents by biological methods. They have eight commercial-scale biological effluent treatment plants in service, under construction and on order at colliery and steelworks coking plants in the United Kingdom and India, and are dealing with enquiries for the treatment of effluents from many other industrial processes.

Monsanto Chemicals Ltd., in the course of developing successful techniques for the biological purification of their own complex effluents, have carried out an intensive research programme for many years. They have successfully pioneered in the United Kingdom processes in which industrial organisations and public authorities throughout the world have long been interested. The research, design, engineering and operating data resulting from this work, and from the continuing operation and development of the massive effluent treatment installations at their factory at Ruabon in North Wales, are now available to all interested parties through the Advisory Service.

PROFESSIONAL APPOINTMENTS

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PROCESS DEVELOPMENT, BRITISH NYLON SPINNERS require well qualified scientists for employment in the Process Development Section of their Monmouthshire factory, and applications are invited from men with good degrees in Chemistry, Physics, Mathematics or Engineering, preferably with some previous industrial experience. The work is interesting and varied and involves the development of new products and processes from the research scale to the production plant, as well as the control and improvement of existing processes. Close liaison is necessary with Research, Engineering and Commercial Departments, and suppliers of raw materials. Good starting salaries will be paid and the continued expansion of production activities ensures excellent prospects for advancement. Generous Pension and Profit Sharing Schemes are in operation and married men can qualify for assistance towards house purchase and removal expenses. The factory is on the same site as the Company's Head Office in pleasant open country and a full range of social amenities is provided. Applications will be treated in confidence and should give details of qualifications and experience. They should be addressed to the Personnel Manager, British Nylon Spinners Ltd., Pontypool, Mon., and should quote Ref. P/238.

A company situated in South Yorkshire, engaged in the heavy engineering industry involving a considerable amount of welded fabrication, wishes to make the following senior appointment.

CHEMICAL ENGINEER to assist in the company's plans for diversification and expansion into proprietary units. This position calls for an experienced man who will be able to direct the design in the early stages and who preferably has some knowledge of vacuum equipment. The company considers that the right man will be approximately 35 years of age but they are prepared to consider applications from younger men who will be able to develop quickly with the opportunities that this position offers. The commencing salary will be in the region of £2,500 per annum, depending upon age and experience.

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The Department organises full-time courses for the Diploma in Technology, the B.Sc. (London) degree and qualifications of the Institution of Chemical Engineers. Research is being developed in collaboration with industry. Plans have been approved for a separate new building for Chemical Engineering which will provide excellent facilities for the extension of teaching and experimental work.

Applicants should be well qualified Chemical Engineers with responsible industrial experience, including that of original design. It would be useful to have previous teaching and/or research experience relevant to the development of under-graduate and post-graduate work in collaboration with industry.

The starting salary will accord with the qualifications and experience of the candidate and will be within the range of Grade V or Grade VI of the Burnham Report, i.e. between £2,100 — £2,500 per annum.

The appointed Head will be permitted to undertake consultant work.

Further particulars and forms of application may be obtained from the Registrar, Bradford Institute of Technology, Bradford, 7.

HENRY PATTEN,
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A HEYWOOD PUBLICATION
British Chemical Engineering

Expansion in the Chemical Industry

IN recent months accounts have appeared on both sides of the Atlantic which have outlined the respective states of health of the North American and British chemical industries.* Needless to say, these reports form the basis of some interesting and in some cases remarkable comparisons between the industries of the two countries.

It is clear that a number of problems confront U.S. chemical manufacturers, the most significant being that of inadequate profitability. One reason for this, a factor which has also operated in the U.K. but apparently with lesser impact, is that construction and operating costs have risen continuously, while the selling price of chemicals has remained stable, the result being that many products have proved much less profitable than original planning had indicated.

Overcapacity, another problem which nowadays afflicts the U.S. chemical industry, is a malady responsible for the intense competition which has kept prices at a low level. Actually U.S. prices in 1960 are at much the same level as they were in 1951. Typifying the overcapacity position are ammonia, plastics and petrochemicals. Until quite recently ammonia plants were almost a mushroom growth in the U.S., and even if demand has risen it is but a proportion of actual capacity, which even now is still being expanded by some concerns in the hope that customers may be attracted away from their present suppliers. The result of all this is a near-catastrophic decline in prices of ammonia products.

Plastics indeed present a similar picture; polystyrene, polyethylene and PVC have attracted a number of new producers, many of whom have merely purchased the relevant processes. The hard consequence is that prices of these commodities have suffered a decline of 25-50%.

On the other hand, the costs of labour and of equipment, many raw materials—even natural gas—have all continued to rise, as have amortisation costs. This situation has evidently taxed the ingenuity of American engineers to the full; attempts have been made to counter the latter difficulty by developing water transport, but here the difficulty has been the expense of the terminal facilities. Other economy-seeking measures have included the long-distance transport of products in suspension by pumping through pipelines bulk carriage of polystyrene granules by freight car in the same manner as wheat.

Other troubles are besetting U.S. chemical manufacturers; for example, interest rates for long-term loans have doubled, and much more has to be spent on customer service.

If the major problems of the U.S. chemical manufacturers are overcapacity and inadequate profitability, what of the British chemical industry? Although our chemical industry shows an annual increase in output in excess of other home industries, this is a sound rather than brilliant performance by comparison with the chemical industries of such countries as Japan, West Germany, France and Italy. On the other hand, this rate of advance exceeds that of U.S. chemical industry, and a closer look at British industry reveals a not unhealthy situation. For example, the manufacture of sulphuric acid, Liebig's suggested index of national prosperity, has risen steadily over the last quarter of a century at a rate in excess of 4% per annum, and shows no sign of slackening.

Of the other heavy inorganic chemicals, the output of ammonia and its salts, which are used mainly in nitrogenous fertilisers, has risen steadily over the past years if at a slightly lesser pace than sulphuric acid. Nevertheless, it is a pace which will almost certainly be maintained. Chlorine, another important inorganic, and a product of the alkali industry, is also being produced in increasing quantities, for over the past decade its output had doubled. In view of a number of expanding outlets for chlorine, such as PVC and hydrocarbon solvents, it is a virtual certainty that the demand for this material will continue to expand.

It is in the organic chemical field, however, that the most vigorous expansion has taken place, and this more than any other single factor is responsible for the high growth rate of the British chemical industry. Petrochemical manufacture, which has more than trebled during the past five years, has contributed to this advance in no small way. It has been the major supplier of raw materials absorbed in organic chemical manufacture, in particular plastics, the sector of chemical industry showing the greatest increase in output with little sign of abatement. In this field too many new products are certain to appear. Polypropylene is one such plastic in the ascendant, and synthetic rubber manufacture will also increase its output several-fold.

By comparison with the U.S. chemical industry the depressing symptoms of over-capacity seem at present to be non-existent, and, if anything, the available evidence points more to a distinct tendency for capacity to lag behind potential consumption. And it is encouraging to find comparatively few complaints upon the part of British chemical manufacturers about the profitability of their ventures. It must be remarked, too, that British consumption of chemicals per head of population is less than it is in West Germany and even more so than in the U.S.

It seems, therefore, that provided no serious obstacles are placed in the way of capital expansion, that the British chemical industry can look forward to an extensive period of prosperity.

* *Inadequate profits prime problem of the Chemical Industry*, C. A. Gerstacker. International Congress of Chemical Engineering, Mexico City, 1960. *British Chemical Industry*, S. P. Chambers. National Provincial Bank Review, August 1960.

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HANDLING AND DISTRIBUTION OF LIQUEFIED GASES

In addition to a number of unit operations, the transference of liquefied gases often makes use of the phenomenon of layering

by T. J. WEBSTER, D.Sc., A.M.I.Chem.E., F.R.I.C., A.F.Inst.Pet.

THE paper will primarily concern the commercial distribution of gases whose critical temperatures are below atmospheric temperature, i.e., gases which cannot be liquefied by pressure alone at atmospheric temperature. In the main, the storage, handling and distribution of liquid oxygen will be discussed, but some reference will also be made to special problems involved in handling other gases such as nitrogen, argon and methane. It would be useful at this stage to look at some of the physical properties of the common gases as shown in Table I to see how these might influence the techniques of storing and handling which can be applied in each case.

Although the species shown in Table I are normally used in the form of gas, the importance of transporting and storing them in liquid form is immediately apparent from the greatly increased bulk density of the liquid over that of the gas in each case, as shown by the gas/liquid volume ratio.

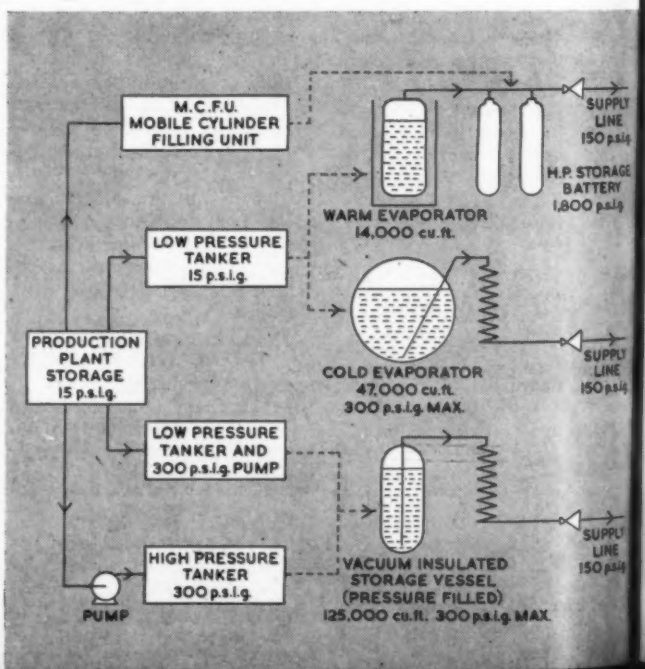
At first sight the boiling points, although low, do not appear to merit special consideration, but boiling point can be most important in operations involving liquefied gases. The fact that the boiling point of nitrogen is lower than the dew point of atmospheric air can, for instance, have an important bearing on the design of liquid nitrogen containers, for if air condenses on the outside of the vessel heat inleak will be increased. It should also be appreciated that air which condenses in contact with equipment containing liquid nitrogen could constitute a combustion hazard, for under the worst circumstances it could contain not 21% but nearer 50% of oxygen. Because of this a non-combustible insulant is often preferred for a tank containing liquid nitrogen, although this gas does not itself support combustion. With proper design the quantity of air liquefying in such cases need amount to no more than a thin film.

The temperature at which gases solidify can be important in deciding whether a particular technique can be adopted. It may, for instance, be desired to cool a gas below its boiling point to assist pumping, and in the case of argon at atmospheric pressure it must be remembered that solidification will occur if the liquid is cooled by only a few centigrade degrees.

Oxygen has a lower freezing point than nitrogen and it is interesting to note that evacuated air has a freezing point some 4°C lower than that of oxygen, a eutectic being formed of composition 23% nitrogen. Thus air can provide deeper refrigeration than oxygen or nitrogen alone.

We may wish to condense one of the above gases using a liquid which comes lower in the boiling point scale and here again freezing point could prove important. For instance, the only easily available liquid which can be used to condense methane and argon is nitrogen, and as the boiling point of nitrogen at atmospheric pressure is lower than the freezing point of either of the other gases special precautions, such as the pressurisation of the nitrogen, might have

Fig. 1. Typical liquid oxygen distribution system.



* Dr. Webster studied at Edinburgh University, then spent six years with the British Petroleum Co., mainly in their Abadan Refining Department. He joined British Oxygen Research & Development Ltd. in 1948 and is now manager of the company's Cryogenic Department.

to be taken to avoid the blockage of plant by frozen gas. Oxygen whose boiling point is lower than that of methane would not be used directly to condense the latter in view of the combustion hazard this would involve.

Density governs the weight of liquefied gas that can be carried in a given container; thus an oxygen container will only provide 37% of its capacity by weight when charged with liquid methane and 70% of its capacity when charged with liquid nitrogen. The liquid/gas volume ratio determines the volume of expanded gas that can be stored as liquid in a container. Thus in terms of gas volume a liquid oxygen container will provide only 80% of its capacity when charged with liquid nitrogen.

Distribution of Liquefied Gases

A liquefied gas is usually produced at some central point from which it is transported by means of an insulated tanker to different points of usage, where it is dispensed in a manner appropriate to the requirements of the user. Most consumers ultimately require gas at about ambient temperature and at a pressure varying between 100 and 200 psig, and it is a prerequisite of any distribution scheme that it should be a simple matter for the consumer to obtain gas under these conditions regardless of the form in which it is originally delivered. Clearly, if the gas is transported as liquid, facilities must be provided for evaporating this liquid in a controlled manner. This can be accomplished in a number of different ways depending mainly on the demand involved. Some of the more important methods of distribution are indicated in Fig. 1.

Where the demand is low the liquid can be transferred from a low-pressure tanker to a warm evaporator where it is evaporated batchwise into a high-pressure storage system from which the consumer can withdraw gas through a suitable pressure-reducing valve. A loss of gas is incurred each time such a vessel is filled. Alternatively, the transport vehicle itself can be provided with a high-pressure pump and evaporator. It then becomes a mobile cylinder-filling unit (termed MCFU in this paper) capable of charging the gaseous product direct into a high-pressure storage battery on the consumer's site. This avoids any filling loss, although there may be a loss connected with cooling down the high-pressure pump. Either of these systems would clearly be unattractive in the case of large users for, apart from other considerations, the cost of the high-pressure storage battery and the space it occupied would become excessive. Where the demand is high, it becomes increasingly attractive to provide, at the point of usage, a liquid storage vessel pressurisable to about 300 psig which may be conventionally or powder-vacuum insulated and this, in turn, calls for the provision of an evaporator and pressure control system to facilitate the evaporation of the liquid. A pressure of 300 psig is called for to provide, first, the potential to force gas into the consumer system at its normal operating pressure of 100-200 psig and, secondly, a reserve of possible pressure elevation to accommodate the pressure increase arising from heat inleak during week-end shut-down periods. Road tankers can normally only be pressurised to about 15 psig; thus to maintain continuity of supply during filling periods with such a system it is necessary to provide duplicate storage vessels which can be used alternately, or a reserve gas storage capacity from which the consumer can draw while the liquid storage vessel is depressurised for re-charging, or to employ a pump on the tanker capable of generating sufficient pressure to overcome the maximum pressure required to be reached in the storage system which, as we have seen, may be of the order of 300 psig.

Finally, as a means of avoiding the necessity for a pump, consideration might be given to the use of a tanker capable of being pressurised to about 300 psig.

Unit Operations in Distribution Schemes

From the foregoing remarks it can be seen that a comprehensive scheme for the distribution of liquefied gas involves a number of unit operations such as:

(a) production;
(b) the storage of liquefied gas at pressures up to 300 psig in static and mobile vessels;
(c) the transfer of liquefied gas at or near its boiling point from vessel to vessel by gravity or by pressurisation;
(d) the pressurisation of vessels containing liquefied gas to pressures up to 300 psig;
(e) the pumping of liquefied gas at or near its boiling point to pressures up to 300 psig or 2000 psig;
(f) the evaporation of liquefied gas at pressures ranging from 100-2000 psig;

Fig. 2. L.O. undercooling at production point.

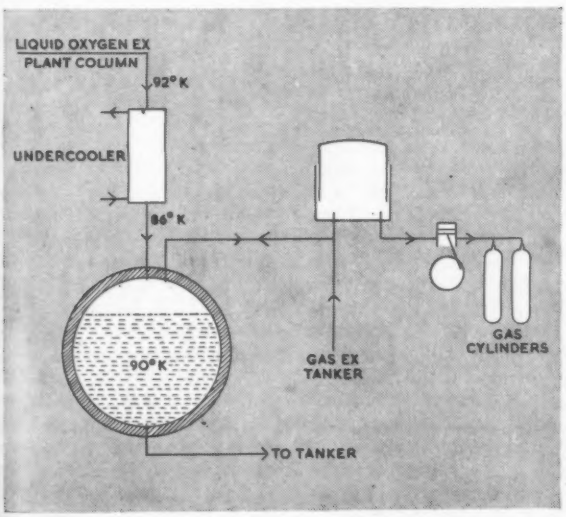
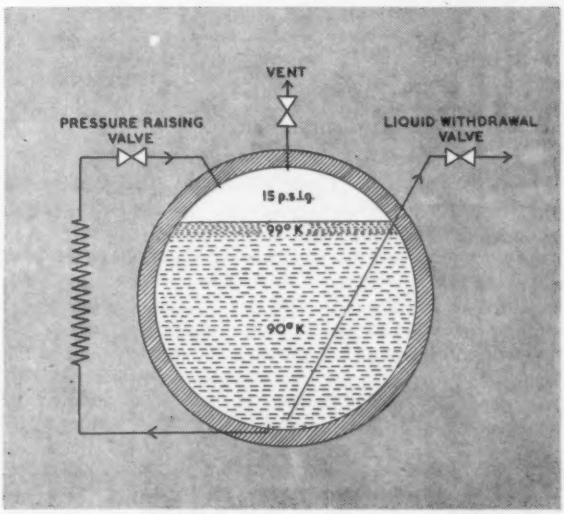


Fig. 3. Stratification in liquid oxygen tanker.



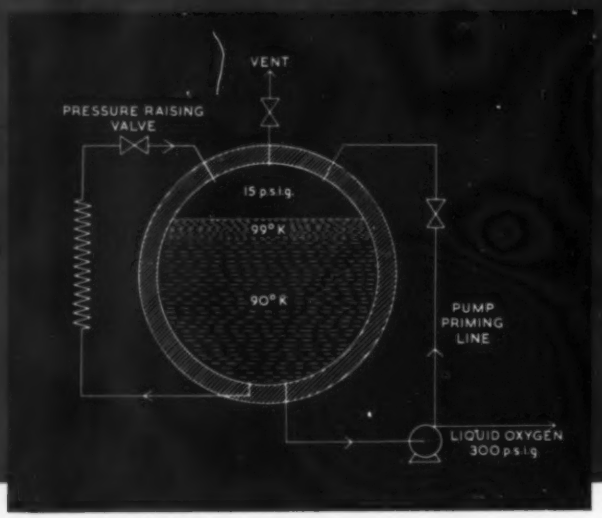


Fig. 4. Liquid oxygen tanker or storage vessel with pump.

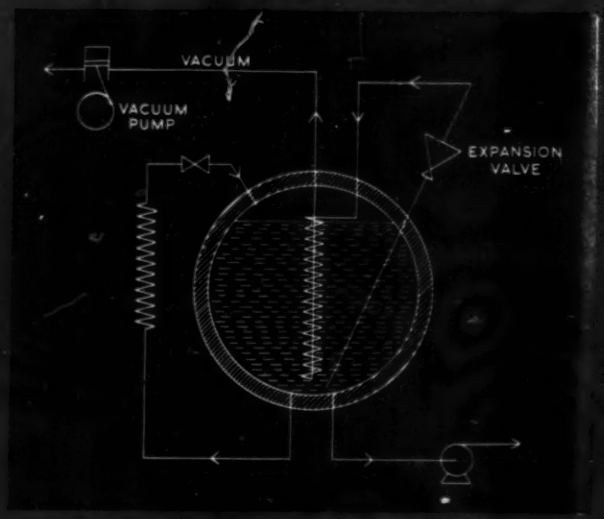


Fig. 5. Undercooling by forced evaporation.

(g) the metering of liquefied gas.

These unit operations present a variety of interesting problems, many of which are by no means obvious at first sight. Before looking at some of these, attention should be drawn to an important difference between the liquefied gas industry and most other industries; namely, the fugitive nature of the product. To consolidate his position the liquefied gas producer must not only make liquid, but ensure that it is delivered to the user quickly in order to avoid loss by evaporation. Unlike many manufacturers, however, the liquefied gas producer can derive some satisfaction from the knowledge that the consumer will in general be unable to "stockpile" his product due to the relatively high cost of storage.

The ultimate aim in the distribution of liquefied gas is usually to provide a completely "no loss" system, but in practice a compromise may have to be made between realising this ideal and keeping capital costs at an economic level, for the acceptance of a new system will depend primarily on whether it can be shown to be economic. Clearly, to achieve minimum loss a distribution scheme based on the use of carefully integrated equipment is essential. There is no point, for instance, in effecting a change which may lead to a reduction in loss at one point in the distribution network if this is more than offset by an increased loss at some other point.

Unit Operations in Liquid Oxygen Distribution

It would now be interesting to look in more detail at some of the unit operations involved in the distribution of liquid oxygen which can be taken as an example of a typical liquefied gas.

Although at first sight production may appear to lie outside the scope of this paper, it frequently happens that production cannot be completely dissociated from distribution. Liquid oxygen, for instance, can be produced either as liquid at its normal boiling point or liquid undercooled by several degrees with respect to its normal boiling point. This undercooling is not obtained without additional cost in power, and if we decide to have it we must ensure that it is employed advantageously.

The Use of Undercooling

The object of undercooling is to eliminate the evaporation loss due to:

(a) the flash gas arising from liquid oxygen leaving the producing plant column which operates at a pressure slightly above atmospheric; and

(b) heat inleak to the storage tank and to the liquid oxygen line feeding the tank.

Undercooled liquid can also be used to recondense gaseous oxygen arising, say, from blowing down tankers at the producing works, and in this connection it should be noted that liquid oxygen undercooled by 1°C will theoretically condense 0.78% of its weight of gas, assuming the gas to be at 90°K.

Liquid oxygen is normally produced at a pressure of about 1.2 atm, at which its boiling point is raised by roughly 2°C; thus 2°C of undercooling are required to suppress the flash which would arise due to the elevated production pressure, leaving any additional undercooling available for the suppression of loss due to heat inleak or for the recondensation of gas which may be introduced to the storage system from an external source. In Fig. 2 undercooling of 6°C with respect to the production temperature has been indicated. It should be noted that undercooling has the effect of increasing the net amount of liquid produced by a liquid oxygen plant—it does not, however, increase the total amount of liquid plus gaseous oxygen produced. In fact, it has the effect of slightly reducing the total oxygen production because of the adverse effect the additional cold production required to provide the undercooling has on the rectification conditions in the plant column. In view of this, one may question the merits of undercooling particularly if gaseous oxygen can be utilised to charge cylinders using a gas compression system. In practice, however, gaseous oxygen compression is not always required or it may be called for only on an intermittent basis; also one has to consider whether it would be advantageous to dispense with gaseous oxygen compression altogether and replace it by liquid compression and evaporation which involves less power consumption than gas compression. These are, however, side issues as far as the present paper is concerned,

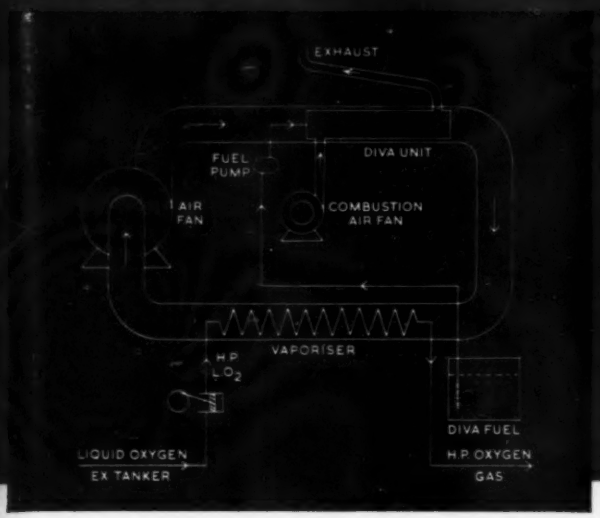


Fig. 6. Mobile cylinder-filling unit.

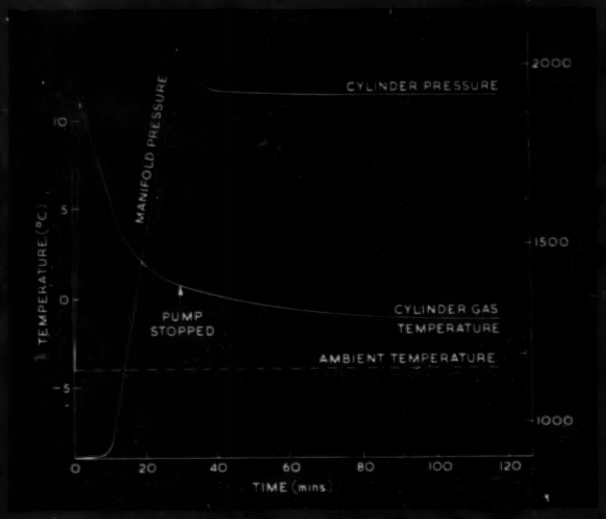


Fig. 7. M.C.F.U. cylinder pressure and temperature vs. time.

but they are worth mentioning as an illustration of the sort of problem with which a liquid oxygen producer is frequently faced. We have seen that undercooling cannot be produced for nothing, and because of this every attempt must be made to utilise it in the best possible way. For instance, it would be valueless to allow undercooled liquid to pass from a plant storage tank into a road tanker unless it could be shown that there was some advantage in operating the tanker on undercooled liquid. In such cases the plant storage system must be operated in such a way as to utilise fully on the production site any undercooling that may be available in the liquid oxygen being produced, and steps should be taken to ensure that undercooled liquid does not find its way into the bottom of the plant storage tank where it would ultimately be lost to the system as tankers were filled. The undercooled liquid could, for instance, be fed into the top of the storage tank through a spray or spreader to prevent it passing down through the bulk of liquid to the bottom of the tank where, due to its high density, it would tend to remain. If top feeding is adopted then not only can undercooling result in the complete elimination of evaporation from the plant storage system, but also it presents the possibility of recondensing gas produced from sources external to the plant such as blow-down from returning tankers.

Transport Vehicles

Under practical operating conditions the tanker represents the first link in the distribution chain. This does not mean, of course, in planning the distribution scheme that one necessarily gives first consideration to the tanker, for usually one would start with the consumer's equipment and then design a tanker capable of supplying this with liquid under the operating conditions involved. At present most tankers used in the liquid oxygen industry are conventionally insulated and capable of being pressurised to about 15 psig. They are usually charged and discharged by gravity with the assistance of a small head of gas pressure which they can withstand. Capacities in the United Kingdom vary from 105,000 cu ft, which is most frequently met, to as much as 300,000 cu ft of liquid oxygen. All tanker capacities given in this paper are in terms of free gas volume measured at 1 atm and 15.56°C.

A simple atmospheric air-heated pressure-raising coil is used to elevate the tanker pressure for discharge. It should be noted, however, that pressurisation is not accompanied, as might be expected at first sight, by an increase in the temperature of the bulk of the liquid oxygen in the tanker, for only a thin layer of oxygen at the surface of the liquid is raised to the equilibrium pressure appropriate to the pressure in the gas space (Fig. 3). This phenomenon, which is usually termed "stratification", has an important bearing on the design and operation of most systems involving the bulk storage of liquid oxygen and more detailed reference will be made to it in the course of the paper. Let us now consider what happens after the contents of the pressurised tanker have been partly discharged to a user. The tanker will be pressurised to its maximum working pressure, but as soon as it starts moving on the road stratification will be partly at least destroyed, the pressure will drop and there may be no need to vent gas before the next customer is reached. On returning to the works with, say 5000 to 10,000 cu ft of liquid contents, the tanker may be fully pressurised but this gas need not be lost, as it can be returned to a holder for compression or recondensation by suitable means.

An obvious limitation of this type of tanker is its inability to discharge into a storage tank pressurised by more than a few psi. This means that a loss must be suffered in venting the liquid receiver, and with a tanker of this type the achievement of a no-loss system is virtually impossible although, of course, it should be borne in mind that the losses incurred in using such a tanker may be quite acceptable on economic grounds as their elimination can some times demand excessive capital outlay leading to an increased overall operating cost. For instance, the reduction in evaporation losses which can be brought about by the use of vacuum insulated tanks may be completely offset by the greater capital outlay which they would normally involve. One way of enabling the tanker to discharge into pressurised equipment is to provide it with a pump capable of discharging at say 300 psig. Such an arrangement is entirely satisfactory from the point of view of the liquid oxygen consumer, for it enables him to operate

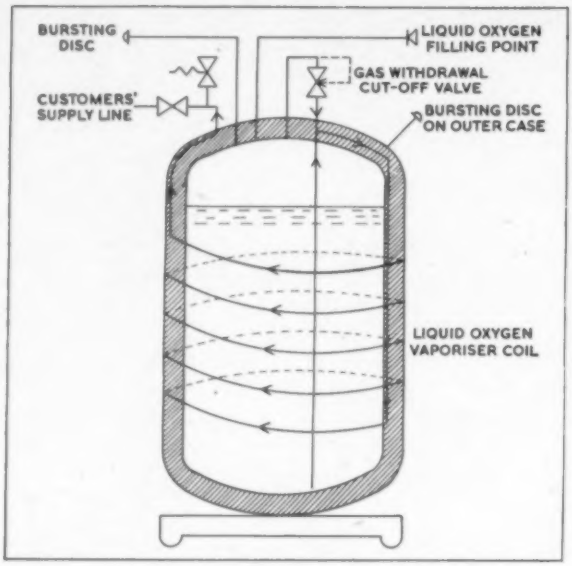


Fig. 8. Functional diagram of small liquid cylinder.

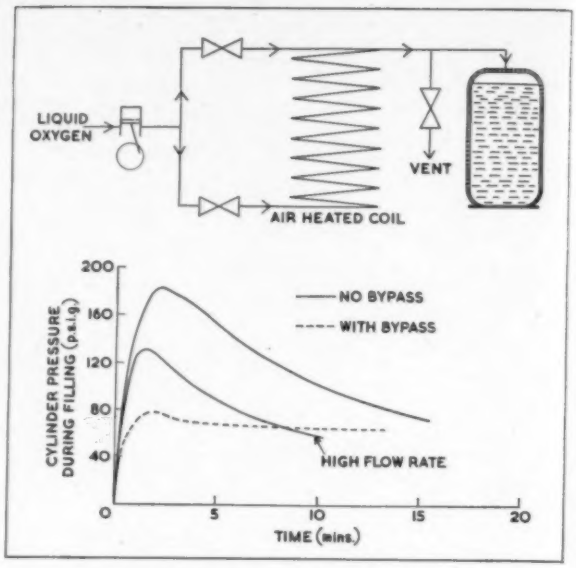


Fig. 9. Filling a small liquid cylinder.

his equipment on a fully continuous basis, but it still involves the supplier in certain losses for the pump has to be cooled down before it will function. It might be useful at this stage to consider some of the factors involved in tanker and static storage vessel discharge by pump (Fig. 4).

Transference by Pump

Because of the high throughput involved in liquid oxygen transfer operations centrifugals are usually employed, and to avoid loss of suction it is essential to avoid boiling or gas formation in the pump suction lines. Thanks to stratification, a considerable degree of liquid oxygen undercooling can be obtained by rapidly pressurising the liquid oxygen in the tanker to be discharged to about 10 psig. It is not sufficient to stipulate that the tank pressure be, say, 10 psig, as in order to derive the maximum undercooling it must be raised to this value from a lower pressure, obtained in the last resort if the pressure is already as high as 10 psig by venting the tank prior to pressurising it. In the case of a road tanker venting will not normally be called for, as the tank pressure will usually drop sufficiently in transit to enable the necessary degree of undercooling to be obtained by pressurising to 10 psig. Clearly, venting should be avoided if at all possible, as it leads to a loss which cannot be recovered.

Once the pump is operating a certain drop in the tank pressure can be tolerated as the effect of heat inleak to the suction line is diminished by virtue of the high liquid oxygen flowrate through it. If, however, the pressure is not sufficient to suppress boiling right up to the impeller, then suction is liable to be lost. If this occurs the tank should be depressurised and repressurised. The use of an external as distinct from an internal submersible pump dictates the provision of a bottom outlet on the tank supplying the pump and unless this outlet is carefully designed the heat inleak to the tank will be greater than for a similar gravity-discharging tank in which a vertical standpipe can be used with no bottom connection other than the relatively small line required for pressure raising. Prior to each pumping operation the pump must be cooled. This can be achieved by opening up the suction line and allowing the gas formed by the evaporation of the liquid to return to the tank vapour space by way of a gas return line. In effect, the pump is used as a pressure-raising coil. Sometimes, however, the amount of gas required for cooling the pump exceeds that required for pressure raising and in these circumstances a loss to the atmosphere must be incurred.

The importance of avoiding branch connections on the suction lines to centrifugal pumps cannot be overemphasised. Branch lines introduce heat inleak and if this leads to local boiling and bubble formation there is a danger that these bubbles will be carried forward to the pump even if the liquid in which they are travelling is adequately undercooled so that the bubbles would condense if equilibrium were established. Suction will be lost if the flowrate of the liquid is such as to allow insufficient time for the gas bubbles to condense before reaching the impeller of the pump.

At first sight the capacity of centrifugal and reciprocating pumps on liquid nitrogen appears to be much lower than on liquid oxygen. Whilst it is true that liquid nitrogen in view of its lower temperature is a little more difficult to pump than liquid oxygen, this is not the main factor responsible for the discrepancy for, as would be expected, it is generally found that the gallons pumped are usually approximately the same in each case. In terms of cu ft gas discharged, this means that the capacity on liquid nitrogen will inevitably be at most only 80% of that on liquid oxygen because of the lower gas/liquid volume ratio of nitrogen.

A liquefied gas pump found satisfactory whilst running will frequently give trouble on being restarted after a shutdown. The difficulty can usually be traced to ice formation on the shaft and in the packing, for although sufficient heat to avoid icing is usually generated when the pump is running this often frequently fails to apply when the pump is shut down and the shaft and gland are receiving only convectional heat from the atmosphere.

Other Methods of Undercooling

We have seen how pressurisation and stratification can combine to provide a marked degree of liquefied gas undercooling in a storage tank. Another method of providing undercooling, say of liquid oxygen, is to make it boil at reduced pressure by drawing a vacuum on the storage tank or, in other words, to make the liquid oxygen act as its own refrigerant (Fig. 5). A disadvantage of this method is

that it necessitates the use of a storage tank itself capable of withstanding vacuum, and this is not always available. We can, however, overcome this difficulty, as shown in Fig. 5, by expanding a portion of the liquid into a coil located in the tank, the coil being maintained at a reduced pressure by a vacuum pump. An advantage of this method is that the pressure-raising coil can be brought into operation to maintain a positive pressure in the tank even when the bulk liquid is cooled below its normal boiling point. We could, of course, undercool a liquid like liquid oxygen by allowing liquid nitrogen (boiling point 77°K) to evaporate in a coil submerged in the liquid, but this would introduce a secondary cooling fluid and usually a completely self-contained system is favoured. Yet another method of cooling the liquid would be by means of a refrigerating engine such as the Philips engine. This, however, has a refrigerating capacity equal to only 5.8 litres/hr of liquid air which might be inadequate for certain applications.

In certain special projects the use of unconventional methods of avoiding boiling in pump suction lines can sometimes be considered. The normal boiling point of liquid oxygen is 90°K but the oxygen partial pressure in atmospheric air is only one-fifth of the atmosphere. Thus it is possible to undercool liquid oxygen by allowing it to evaporate into freely circulating air. By spraying a pump suction with oxygen we can therefore obtain extremely satisfactory suction conditions. Theoretically a temperature of 78°K, i.e., 12°C below the boiling point of oxygen, can be obtained in this way. In cases where the use of oxygen might be considered undesirable the suction line could be sprayed with liquid nitrogen. It is worth noting that spraying is one of the few methods which can be used to provide a complete barrier against heat inleak from the atmosphere —this is more than can be achieved, even theoretically, by the best insulation.

Pumping Problems

There is one important difference between the behaviour of a centrifugal pump used to pump a low boiling point liquefied gas and a liquid whose boiling point is above ambient temperature. If the boiling point of the liquid is above ambient temperature, one can usually obtain almost infinite variation in pump output by adjustment of the pump discharge valve. This does not apply in the case of a centrifugal operating on low boiling point liquefied gas, for it is generally found that if the pump is throttled by a relatively small degree then suction will be lost. The reason for this is that all centrifugals suffer a certain amount of impeller slip or by-passing and this effect becomes more marked on throttling as the pressure differential across the pump is increased. When the fluid being pumped has a boiling point above ambient temperature this has little effect on the suction condition, but with low boiling point liquefied gas the enthalpy increase suffered by the liquefied gas in passing from a low- to a high-pressure stage may well be sufficient to cause flashing of any liquid which slips back from the high pressure to the preceding low-pressure stage and the effect of this would be loss of suction. The effect is aggravated by churning at low throughputs. The practice of over-designing a pump to ensure that it will be man enough for the job can therefore be indulged in to only a limited extent where low-temperature liquids are concerned, otherwise the operator may find himself forced to accept throughputs far in excess of his requirements. The effects of impeller or interstage slip can, of course, be minimised by allowing the pump to have its head, assuming there is no throttling resistance on the discharge side, but if we overdo this, suction is liable to be lost, as with the higher boiling point liquids, by the depression of suction pressure which results.

Metering

It might be appropriate to say a few words about metering at this stage, for what has been said about the importance of avoiding gassing in the pumps also applies in the case of liquid oxygen meters. For metering liquid oxygen, consideration can be given to the use of orifice meters, modified water meters, such as the oscillating piston type, or the type with intermeshing helices, also rotameters which can be provided with magnetic or mechanical pick-ups, and turbine meters such as the Potter meter. The point of installation of a meter is of vital importance and it should only be placed where sub-cooling can be guaranteed, e.g., near a pump on the discharge side. Most meters can be made to work satisfactorily under normal operating conditions particularly if steps are taken to ensure that the fluid they are metering is adequately undercooled—difficulty arises, however, in starting up and shutting down when serious gasification is liable to occur which may cause the meter to race to destruction. The elimination of gear trains and the use of magnetic drives and electronic pick-ups such as that employed in the British Oxygen Co.'s Limpet meter (Liquid Integrating Meter Positive Electronic Transmitting), which is a modified water meter employing an oscillating piston, enables meters to be made which are robust enough to stand up to racing. In the case of turbine meters the bearing design is of paramount importance and the success of the meter depends on the cryogenic "know how" that has gone into its construction. Simple orifice flow meters are quite satisfactory provided the impulse leads are arranged in such a way as to avoid surging or the introduction of spurious hydrostatic heads. A certain amount is being done on mass-flow meters and on meters based on acoustic and paramagnetic effects, but all these types will require a considerable amount of development before they can be considered industrially.

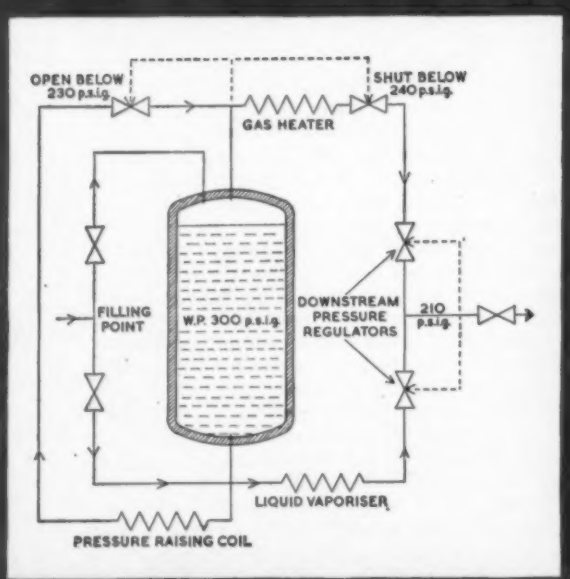
Users' Equipment

Some of the problems associated with the design and operation of the equipment used for dispensing oxygen to customers will now be considered. For small users the warm evaporator has been used for a considerable time, but it is now being superseded by more highly developed forms of equipment. It will be recalled that the warm evaporator provided a means of charging a battery of storage cylinders with high-pressure gas from which the user could draw supplies by way of a simple reducing valve. Mobile cylinder filling units (MFCUs) have been developed which enable users' storage batteries to be charged direct with high-pressure gas from a transport vehicle carrying liquid oxygen, thus eliminating the need for warm evaporators and avoiding the losses associated with their use. The operating principles of the MFCUs can be seen from Fig. 7.

Mobile cylinder filling units have been in use in the U.S.A. for some time and are capable of delivering about 25,000 cu ft/hr of oxygen, using engine cooling water and exhaust heat for vaporising the compressed liquid system. A diesel-engined unit with an output up to 40,000 cu ft/hr of compressed gaseous oxygen at 2000 psig has been developed in this country by British Oxygen Research & Development Ltd. To provide sufficient heat economically for such a unit from the engine would have presented technical difficulties and would certainly have imposed a heavy burden on the engine. A commercial oil heater as used for aircraft space heating was chosen to provide the large heat release (half-million Btu per hr) required to accomplish evaporation. This had a further advantage of enabling a cheap, untaxed fuel to be used and avoided the necessity for using engine heat which results in high maintenance charges.

The unit comprises a 100,000 cu ft powder-insulated aluminium tank mounted on a diesel-engined chassis with

	B.P. at 1 atm °K	M.P. °K	Density of Liquid at B.P. gm/cc	Volume of gas at 1 atm and 15.56°C from evaporation of 1 cu. ft of liquid cu ft	Latent heat of vaporisation cal/gm
Methane	112	91	0.42	620	122
Oxygen	90	54	1.140	843	51.0
Argon	87	84	1.39	824	39.0
Air (dew point)	81	50 (eutectic)	—	715	49.0
Nitrogen	77	63	0.808	682	47.6



a three-throw reciprocating pump capable of delivering 40,000 cu ft/hr of liquid oxygen at cylinder pressure (Fig. 7). The compressed liquid oxygen is evaporated in an exchanger by a heated air stream, the air being recirculated by means of a fan through the oil-fired heater. It was necessary to convey the heat from the burning oil to the liquid oxygen vaporiser indirectly in this way in order to avoid the precipitation of the products of combustion which would otherwise have occurred on the low-temperature surfaces of the vaporiser. Even with the system employed, any carbon dioxide and water vapour initially present in the air stream being recirculated will be deposited on the cold surfaces of the vaporiser, but the amount of material deposited in bringing the air up to such a high degree of purity as to prevent further deposition will be very small. The system is compact and carries a relatively low weight penalty; it facilitates an almost instantaneous start-up and is safe to operate.

An MCFU enables customers' storage batteries to be charged with high-pressure gas directly from a liquid-carrying tanker.

The gas charged to cylinders is normally invoiced by the pressure increase, and in view of this it is desirable that the temperature of the cylinder battery should be nearly ambient after charging. To achieve this it is necessary to control the temperature of the oxygen leaving the MCFU at around −10°C, depending on ambient conditions, to compensate for the heat of the compression in the cyclinders being charged.

Fig. 7 shows graphically the temperature and pressure changes in a cylinder during the charging operation. Initially, a marked temperature rise occurs due to the fact that the inlet gas temperature has not fallen to the control value, then the temperature falls off and with proper control there is no difficulty in ending up at about ambient temperature on completing the fill.

With such a system safeguards must be provided to protect the cylinders from excessively cold gas or even liquid oxygen which might be charged in the event of failure of the heating circuit.

Another system which has been developed in America and is being introduced in this country to meet the requirements of the small user, relies on the use of a small liquid container pressurisable to about 300 psig and very efficiently insulated with a vacuum-powder insulant. Typical of these is a vessel which holds 3000 cu ft of liquid oxygen (see Fig. 8) and which can withstand a maximum pressure of 234 psig, allowing a period of about 100 hr before blow-off from the normal operating pressure, which is about 75 psig. In operation, if due to standing the pressure exceeds 75 psig, the gas withdrawal cut-off valve opens, allowing gas to be withdrawn preferentially to liquid, and when the pressure falls to 75 psig this valve shuts, conserving gas pressure and allowing only liquid to be withdrawn from the vessel. An important feature of the liquid cylinder shown is that it employs no pressure-raising coil. This assists in reducing heat inleak to the unit and thereby extends the standing period before gas blow-off, but it means that the vessel must be charged with preheated liquid oxygen to ensure that sufficient pressure will be maintained in it to effect discharge of the contents. In filling such vessels the object is to end up with a cylinder of liquid fully "stabilised" at a pressure of about 70 psig. If the liquid is not fully stabilised, then a serious pressure drop will occur if the liquid surface is disturbed as must inevitably happen during transport. Clearly, to achieve this the cylinders must be pump filled through a heater, but this apparently straightforward procedure involves certain difficulties which may be worth looking at.

Fig. 9 shows diagrammatically how a liquid cylinder may be filled using a pump which can be reciprocating or cen-

trifugal and an atmospheric air-heated coil provided with a by-pass employed to limit the pressure rise which tends to occur during the initial stages of filling.

From the graphs it can be seen that there is a marked tendency for the pressure in the cylinder to rise at the commencement of filling. At low filling rates (see top graph) this can be great enough to necessitate blow-off during filling. At high filling rates (centre graph) the peak pressure reached becomes less but there is a danger of not ending up with sufficient pressure in the cylinder. If a larger coil is used to provide more heat inleak and thus correct for this lack of final pressure, there is a danger of peak initial pressures in excess of the cylinder blow-off value being generated. Use of an adequate heating coil provided with a by-pass enables these difficulties to be overcome, as is evident from the lower graph. The diagram shows how, by employing the by-pass at the start of filling, peak pressures can be almost completely eliminated. The by-pass valve can be automatically controlled by the cylinder pressure.

Fig. 10 shows a general view of a typical small liquid cylinder. The unit shown has a capacity of 3000 cu ft and is capable of delivering gas at a steady rate of about 350 cu ft/hr. Where demands are in excess of that capable of being met by one such vessel, a number of vessels can be manifolded together.

Industrial Liquid Dispensing Unit

It would now be appropriate to look at the latest type of equipment available for users of large quantities of liquid oxygen which is evaporated to meet a high demand for gaseous oxygen.

The unit as shown in Fig. 11 essentially consists of a vacuum powder-insulated stainless-steel vessel (maximum working pressure = 300 psig) from which liquid or gaseous oxygen can be withdrawn through a vaporiser and gas heater respectively. A conventional pressure-raising circuit is actuated automatically when the pressure in the vessel falls below a predetermined value, say 230 psig; otherwise the circuit remains closed. This ensures that there is always sufficient pressure in the vessel to drive liquid through the vaporiser to the consumer. A pressure regulator located after the vaporiser controls the amount of liquid withdrawn from the storage vessel according to consumer demand.

After a period of standing the pressure in the vessel will tend to rise above the value necessary for normal operation, and to check this effect the control valve in the gas withdrawal line after the gas heater is set to open at pressures above say 240 psig, allowing gas to pass directly from the gas space in the storage tank to the consumer when a demand occurs.

Let us consider the reason for developing a unit of this type.

Basically, the problem was to provide a no-loss system which could supply a customer automatically with gaseous oxygen at a pressure of about 200 psig, which could be filled without interrupting the supply and which could remain shut down for at least 2½ days without blow-off to the atmosphere to provide for week-end periods when there might be no demand. The fact that the unit had to be filled using a centrifugal pump fixed the maximum pressure at 300 psig, giving a permissible pressure rise of about 100 psig above the normal working pressure to accommodate heat inleak during shut-down. An 8-day blow-down period was built into the actual unit. Now it is important to note that the rate of pressure rise of a vessel containing liquid oxygen for a given amount of heat inleak is dependent on:

(a) the degree of stratification of the liquid; and

(b) the quantity of liquid in the vessel.

The degree of stratification becomes less as the rate of heat inleak is reduced. Thus if we reduce the rate of heat

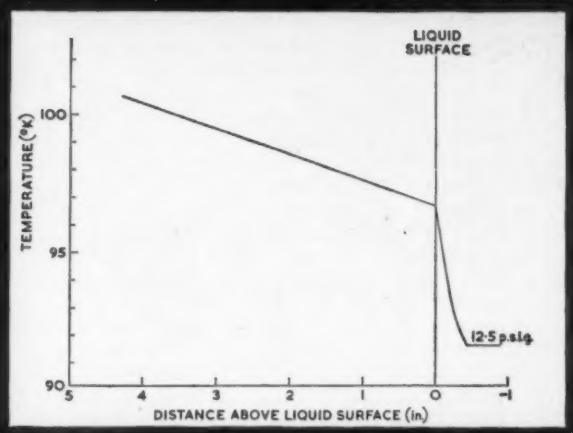


Fig. 12. Temperature gradients near surface of pressurised liquid oxygen.

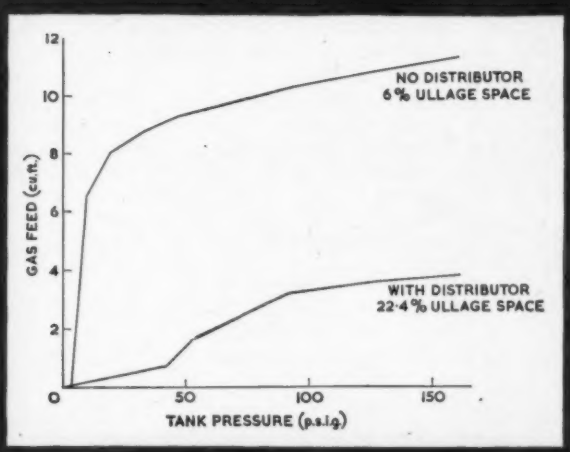


Fig. 13. Effect of distributor on pressurising gas requirement.

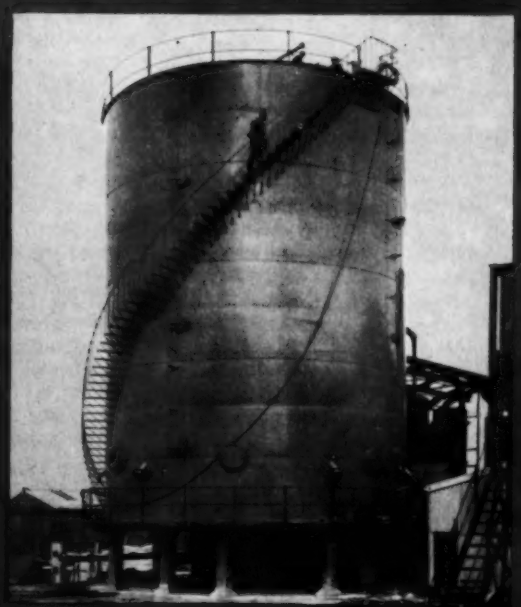


Fig. 14. 15,000,000 cu. ft capacity powder-insulated liquid oxygen storage tank.

inleak to the vessel we actually increase the total amount of heat which its contents can absorb for a given increase in pressure. This adds to the more commonly accepted advantages of the vacuum insulation. A further reduction in heat inleak accrues from the rise in the bulk liquid temperature with rising pressure. Thus not only does vacuum insulation reduce the rate of heat inleak, but also it leads to an increase in the total amount of heat absorbed over that which could be absorbed with less effective insulation.

There is nothing we can do about (b), the quantity of liquid in the vessel, but it is perhaps worth mentioning that the rate of pressure rise of a full vessel is usually less than that of a partly filled vessel because the amount of sensible heat inleak which can be absorbed by the greater quantity of liquid in the full vessel considerably exceeds that which can be absorbed in a partly filled vessel, and this effect more than compensates for the greater gas space available in the case of the partly filled vessel. This result is achieved despite the fact that the rate of heat inleak to a full vessel slightly exceeds that to a partly filled vessel because more of the inner wall is cooled to the liquid temperature; this effect becomes less marked with improvement in insulation and may be almost insignificant in the case of a well-designed powder vacuum tank. In assessing the performance of a vessel, it is desirable to test it when filled to different levels.

Referring to the filling operation, under the worst conditions the vessel pressure may be 300 psig prior to the fill and it might be expected that an attempt to fill it would result in a gas blow-off. Such might be the case if the liquid were charged to the bottom of the vessel, but if at the commencement of filling we spray a small amount of the pumped liquid (which, it should be remembered, will be at a temperature only slightly above 90°K) into the gas space it will immediately condense some of the gas and rapidly reduce the pressure. In practice the pressure can be maintained at any desired value during filling by adjustment of the two liquid inlet valves.

Stratification

Of all the phenomena encountered in the storage and handling of liquefied gases, stratification is one of the most important and it is certainly the most elusive. It is elusive in so far as one can never be certain as to the degree of stratification that is going to be built up in a particular vessel without carrying out extensive trials under carefully controlled conditions.

Typical of many experimental determinations of stratification are the results shown in Fig. 12, where the temperature occurring on either side of the interspace of liquid oxygen in a vacuum-insulated container immediately after pressurisation to 12.5 psig is plotted against distance from the interspace.

The rapid fall in temperature in the layers of liquid within inches of the surface indicates how thin these stratified layers can be and explains how easily they can be broken up in certain instances.

As an example of one of the difficulties which stratification can cause, it is interesting to consider the case of a pressure vessel containing liquid oxygen at 50 psig provided with a small heater immersed in the liquid near the bottom of the vessel. On introducing heat a marked reduction in pressure is obtained due to the disturbance of the stratified layer by the convection current set up by the heater. A similar effect can be obtained by simply shaking the vessel. In fact, this is one of the methods that are used to determine the degree of stratification in a vessel.

Stratification also influences the discharge of liquefied gas from vessels by gas pressurisation—for instance, the discharge using gaseous oxygen or gaseous nitrogen at constant pressure of liquid oxygen in a container pressurised to 100 psig. What do we find? At the commencement of discharge the pressure drops slightly and we admit more gas to correct this. Depending on conditions and on the geometry of the tank and the inlet line, the more gas we admit, the faster the pressure drops and the system can become completely unstable. This is due to the churning up of the stratified layer by the jet of pressurised gas which immediately condenses in the cold liquid exposed by the removal of the stratified layer. Increasing the rate of gas addition increases the rate of churning and speeds up the rate of condensing of the gas, with the result that it becomes increasingly difficult to maintain pressure. This difficulty can be overcome by fitting a diffuser.

A convincing indication of the value of a diffuser in reducing the amount of gas required to pressurise a vessel containing liquefied gas is given in Fig. 13, which compares graphically the pressurisation gas requirement to achieve different pressures in an experimental vessel with and without a diffuser. The gas requirement in the experiment in which the diffuser was fitted can be seen to be much less than that in the test where no diffuser was fitted. Furthermore, this result was achieved despite the fact that the ullage space in the former run was considerably greater than in the latter. It should be mentioned that in the above study the distributor was located as near to the liquid surface in the 22.4% ullage run as the normal vent in the 6% ullage run. Thus the reduction in gas requirement could not have been caused by a difference in the distance between the gas inlet and the liquid surface in the two experiments.

Modern Storage Tanks and Transporters

The ever-increasing demand for liquefied gases such as liquid oxygen has resulted in a requirement for very large storage tanks and liquid transport vehicles. Typical of these are the British Oxygen Gases' 15 million cu ft liquid oxygen storage tank (Fig. 14) and 300,000 cu ft liquid oxygen transporter.

The erection of the storage tank on piers as a safeguard against the cooling and freezing of ground underneath is of particular interest and represents a technique which can now almost be regarded as standard practice where the design of large tanks is concerned. It was employed, for instance, in the case of the 800-ton North Thames Gas Board tanks erected for the storage of liquid methane in this country.

ACKNOWLEDGMENT
The author is indebted to the Directors of British Oxygen Research & Development Ltd. for their permission to publish this paper.

Errata: "Thermal Dehydrochlorination of Ethylene Dichloride"

IN the above article by L. K. Doraiswamy, P. H. Brahme, M. U. Pai and S. Ondeambaram in the September 1960 issue of this journal, pp. 618-23, under the heading "Thermodynamic Considerations", it is stated that the results of equilibrium calculations made by Tatevskii and Frost are plotted in Fig. 3 (page 619). This should be Fig. 1.

The units of k, under "Symbols Used" (page 620), the first-order rate constants are given as litres/hr^2 which should, of course, be hr^{-2}, and the units of S_v in Table I (p. 621), should be reciprocal hours and not litres per hour.

In Equation 7 (page 622) K should be replaced by k, and in Table II, "Summary of Equations", the second equation, correctly stated in the text, should read:

$$\frac{1}{S_v} = \frac{1}{k} \ln \left(\frac{1}{1-x} \right).$$

536.75:661.937

ENTROPY — A THERMODYNAMIC CONCEPT AND ITS APPLICATION

A simple restatement of this concept is followed by examples of its use in evaluating refrigeration cycles

by W. STRAUSS*, M.Sc., M.E., Ph.D.

THERMODYNAMICS is the study of energy changes—particularly heat changes—in macroscopic systems and their surroundings. The classical system developed in the last century uses idealised concepts of "systems in equilibrium" and "changes carried out reversibly" to obtain conclusions which are important in practice, although the idealised concepts are hardly ever met with. (An important exception to this is the potentiometric measurement of e.m.f.) Recent developments in thermodynamics, however, have been chiefly concerned with the methodology of spontaneous or irreversible processes. This particularly emphasises the importance of the entropy concept in flow processes, which will be dealt with in the last part of this article.

The familiar classical approach to the question "What is entropy?" is retained here, but the ideas are extended in an attempt to incorporate some recent developments, and to apply these to an example, viz., the most economic method of producing liquid oxygen from air.

Definitions

Variables such as composition (n) and the quantity (m) of the components of a system (which is a body of matter distinct from its surroundings), its volume (v), pressure (p) and absolute temperature (T) completely define the thermodynamic state of a system by an equation having the general form:

$$f(n, m, v, p, T) = 0 \qquad \ldots . (1)$$

In the usual system encountered in heat engines, the quantity and composition of the system remain constant, and the general Equation (1) can be written more specifically as:

$$f(v, p, T) = 0 \qquad \ldots . (2)$$

which can be rewritten as:

$$f'(p, v) = T \qquad \ldots . (3)$$

that is, any one of the three variables p, v or T can be expressed in terms of the other two. For an ideal gas the relation

$$p \times v = \text{constant} \times T \qquad \ldots . (4)$$

is thus its equation of state, with the constant being the universal gas constant, R.

The "state functions", such as enthalpy or heat content (H) and intrinsic energy (U), for a system are those that can be expressed in terms of m and n, and of two independent variables p, v or T. The entropy (S) of a system is one of these thermodynamic state functions, but, unlike intrinsic energy or heat content, it is not a readily imaginable concept.

The First Two Laws of Thermodynamics

While the first law of thermodynamics is simply a statement of the principle of the conservation of energy, the second law is not so easily defined, as it is a law based on complex experiences, for example, to recognise that it is impossible to take heat from a cold body and give it to a hot one (i.e., to drive a ship using the heat of the ocean) or more fundamentally it is the law which expresses the fact that a spontaneous process cannot reverse itself. This postulates that there is a function, the total value of which must always increase for a spontaneous process, i.e., a process which is not carried out reversibly. This function is called entropy. Clausius, who introduced this function in 1851, stated the argument of the two laws very neatly: "The energy of the universe is constant; the entropy of the universe tends to a maximum."

The Calculation of Entropy

In the classical (i.e., nineteenth century) approach, the entropy change in a system undergoing a process was calculated by considering the process as part of a cyclic process, such as the Carnot cycle, carried out on an ideal gas (Fig. 1). In such a cyclic process each stage of the cycle is carried out reversibly, so that maximum work may be obtained for the theoretical minimum of effort. In the Car-

* Dr. Strauss graduated at Melbourne University and did his post-graduate studies at the Universities of Sydney and Sheffield. He is now a research officer with C.S.I.R.O. Chemical Engineering Section in Melbourne, Australia.

not cycle, the first stage is the isothermal expansion of an ideal gas (see the pressure-volume diagram—Fig. 1) at a temperature T_1, during which the external work done, W_1, is

$$W_1 = \int_{v_1}^{v_2} p\,dv$$
$$= RT \ln v_2/v_1 \quad \ldots.(5)$$

To enable the isothermal expansion to be carried out, an amount of external heat, Q_1 (which is equal to W_1 as the process is carried out reversibly), is taken from a reservoir or source. Stage II is the adiabatic expansion of the ideal gas, between temperatures T_1 and T_2, during which no external heat is required, and the work done, W_2, is

$$W_2 = C_v(T_1 - T_2) \quad \ldots.(6)$$

C_v is the specific heat of the ideal gas. During Stage III the ideal gas is compressed reversibly and is thermally at the temperature T_2, so the work done, W_3, is

$$W_3 = \int_{v_3}^{v_4} p\,dv = RT_2 \ln v_4/v_3 \quad \ldots.(7)$$

During the compression heat, Q_2 (which is equal to $-W_3$) is given up to the reservoir. Stage IV is the adiabatic compression of the ideal gas, in which the gas is returned to its initial state, and the work done, W_4, is

$$W_4 = C_v(T_2 - T_1) \quad \ldots.(8)$$

which is seen to be $-W_2$.

The total work done during the cycle is the sum of the amounts during the stages. As all the stages were carried out reversibly, the total reversible work, W_r, is

$$W_r = W_1 + W_2 + W_3 + W_4$$
$$= W_1 + W_3 \quad \ldots.(9)$$
$$(\text{as } W_4 = -W_2)$$

Also, Q_r is the amount of heat taken from the reservoir, i.e., the amount taken in Stage I, less the amount $(-Q_2)$ returned in Stage III; viz.:

$$Q_r = Q_1 - (-Q_2) = Q_1 + Q_2 \quad \ldots.(10)$$

(the positive sign of Q_2 being obtained from the convention which regards heat adsorbed as positive) and Q_r is equal to the amount of work, W_1, performed during the cycle, thus

$$W_r = Q_1 + Q_2$$
$$= W_1 + W_3 \quad \ldots.(11)$$

Since v_1 and v_4 lie on one adiabatic curve and v_2 and v_3 on another, it can be seen, from the equation for the adiabatic expansion of an ideal gas, $Tv^{\gamma-1}$ = constant, that

$$\left(\frac{v_4}{v_1}\right)^{\gamma-1} = \frac{T_1}{T_2} \text{ and } \left(\frac{v_3}{v_2}\right)^{\gamma-1} = \frac{T_1}{T_2} \quad \ldots.(12)$$

so

$$\frac{v_4}{v_1} = \frac{v_3}{v_2} \text{ or } \frac{v_2}{v_1} = \frac{v_3}{v_4} \quad \ldots.(13)$$

Hence

$$W_r = Q_1 + Q_2 = W_1 + W_3$$
$$= R\,T_1 \ln (v_2/v_1) + R\,T_2 \ln (v_4/v_3)$$
$$= R(T_1 - T_2) \ln (v_2/v_1) \quad \ldots.(14)$$

Since

$$Q_1 = W_1 = RT_1 \ln (v_2/v_1) \quad \ldots.(15)$$

Dividing Equation (14) by Equation (11) gives

$$\frac{W_r}{Q_1} = \frac{Q_1 + Q_2}{Q_1} = \frac{T_1 - T_2}{T_1} \quad \ldots.(16)$$

The importance of this relation (16) is that it equates the amount of heat taken at the source (or higher) temperature to the maximum amount of work available from the reversible cycle, and that the right-hand side of the equation, $(T_1 - T_2)/T_1$, contains only the temperatures of the source and the sink. (or upper and lower temperatures of the cycle, or in more general terms, all ideal, periodic machines, working reversibly between the same temperatures, have the same efficiency. This is a statement of Carnot's theorem, and W_r/Q_1 is called the Carnot efficiency of the process.

Equation (16) may be transformed to give

$$\frac{Q_1}{T_1} + \frac{Q_2}{Q_2} = 0 \quad \ldots.(17)$$

or, more generally, for a multi-stage process (Fig. 2)

$$\frac{Q}{T} = \int_A^C \frac{dQ}{T} + \int_C^A \frac{dQ}{T} = \oint \frac{dQ}{T} = 0 \quad \ldots.(18)$$

It can be shown that the integral $\int_A^C dQ/T$ is independent of the path between C and A, and only depends on the states of C and A; and by definition the change in entropy in passing from A to C is given by

$$S = S_A - S_C = \int_A^C \frac{dQ}{T} \quad \ldots.(19)$$

from which it follows that $dS = dQ/T$ $\quad \ldots.(20)$

Does entropy defined in this way have the property, stipulated in the introduction, of always increasing for a spontaneous process? For the change from A to C to be carried out in finite time, it must be carried out irreversibly, and some heat must either be dissipated to the surroundings or taken from them. Thus there is an overall increase in heat, and dQ/T $(= dS)$ is positive, and the stipulation is satisfied. In contrast to this, for a reversible change taking place in an isolated system, the total entropy remains constant; i.e.

$$dS > 0 \quad \ldots.(21)$$

So entropy changes can be of two types—those due to changes within a system, and those due to the interaction of a system with its surroundings. It is important to note that entropy is an extensive property, i.e., the total entropy of a system containing a number of sections is equal to the sum of the entropies of the parts.

The classical approach to the entropy function outlined above, which is the most familiar one, is rather clumsy and leaves a number of loopholes. A much more elegant approach to this abstract parameter has been outlined by Prigogine.[1] Entropy is defined by Equation (20), and it is then shown that this term has certain properties required of it by the second law of thermodynamics.

The most fundamental approach regards entropy as the measure of the state of chaos or randomness of the molecules in a system, and this forms the basis of statistical mechanics. It is therefore possible to regard all spontaneous processes as leading to an increase in the random distribution of molecules. Since a disordered state is more probable than an ordered one, entropy and probability are related, and Boltzmann (in 1896) defined the thermodynamic probability W of a sytem as the ratio of the probability of an actual state to one having the same total energy and volume, and in which the molecules are ordered. As entropy is an extensive property, and the entropies of the parts of a system are additive, while probabilities are multiplied, the relation between entropy and probability is logarithmic, and it may be written as

$$S = k \ln W + \text{constant} \quad \ldots.(22)$$

Boltzmann was able to show that k is the universal gas constant per molecule (R/N, where N is Avogadro's Number). If it is assumed that entropy depends only on thermodynamic probability,

$$\text{then } S = k \ln W \quad \ldots.(22a)$$

Thus for a completely ordered system, which could exist in a crystalline solid at the absolute zero of temperature, $W = 1$, and the entropy is zero. This may be regarded as one statement of the third law of thermodynamics.

By using this third law of thermodynamics, it is possible to calculate an absolute value for the entropy of a system. When the temperature of a solid is increased, it first liquefies, and then vaporises, each stage in the process being accompanied by an increase in entropy. If $\triangle H_f$ is the latent heat of fusion, the entropy increase for melting is $\triangle H_f/T_f$ where T_f is the melting temperature. Similarly, at the vaporisation temperature, T_v, the entropy increase is $\triangle H_v/T_v$, where $\triangle H_v$ is the latent heat of vaporisation. So for a gas, the absolute value of the entropy S at a temperature T can be found from

$$S = \int_0^{T_f} C_s \, dT/T + \triangle H_f/T_f + \int_{T_f}^{T_v} C_l \, dT/T + \triangle H_v/T_v + \int_{T_v}^{T} C_g \, dT/T \qquad \ldots (23)$$

where C_s, C_l and C_g are the heat capacities, at constant pressure, of the crystalline solid, the liquid and the vapour respectively.

However, an engineer working with steam and refrigeration cycles is interested in entropy changes rather than absolute values. Also, engineers had been using entropy values for fifty years before the statement of the third law of thermodynamics. The values of entropy given in steam tables and refrigerant property tables are therefore not based on the absolute entropy values, based on the absolute zero, 0°K (or R). Steam tables and those for carbon dioxide use 32°F (0°C or 273.16°K) as their arbitrary zero, while tables of properties of refrigerants use −40°F (which is also −40°C) as their zero value. The negative entropies listed in some of these tables are the relative entropies for the substances at temperatures below the arbitrary zero. Entropies using the arbitrary zero temperature can be calculated using various combinations of the terms in Equation (23); i.e., for steam tables the last three terms tracing the path of heating liquid water at 32°F to steam at the required temperature would be used. The entropy change involved in a change in pressure can be worked out from Equations (5) and (20).

Application of the Concept of Entropy and Irreversibility

The application to the evaluating of refrigerating cycles using entropy changes in irreversible processes will be discussed here. The simple vapour compression cycle (Fig. 3) is shown in the entropy-temperature diagram (Fig. 4). In Stage I, the cold refrigerant vapour absorbs heat in the refrigeration cabinet; in Stage II it is compressed adiabatically (at constant entropy); liquefied (here complete liquefaction is assumed) in Stage III in a water- or air-cooled heat exchanger; and then expanded in Stage IV. This expansion may be either adiabatic (IVA), using an expansion engine, or isenthalpic (i.e., at constant enthalpy), through a throttling valve (IVB) to return to the beginning of Stage I. The isenthalpic expansion is irreversible, and its detailed theoretical working will be discussed below. In a theoretical case, using ammonia as a working fluid, isenthalpic expansion causes about 15-20% more energy to be used for the same amount of refrigeration effect. However, no real expansion engine is truly adiabatic, nor is the reconversion to work 100%, so any actual gain is far less than this. As an expansion engine and reconversion system is both complex and very costly, compared to a throttling valve, its commercial use is very rare. However, with very large plant capacity, as is the case in oxygen liquefaction, both expansion engines and throttling valves can be used simultaneously in parallel. Another example where an expansion engine is used rather than a throttling valve is in decompression of ammonia made at high pressures by the Haber-Bosch synthesis.

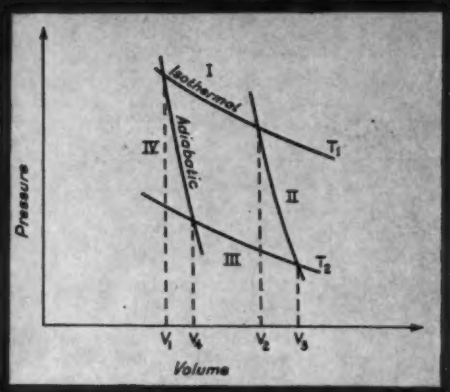


Fig. 1. Pressure-volume diagram showing Carnot's cycle carried out on an ideal gas.

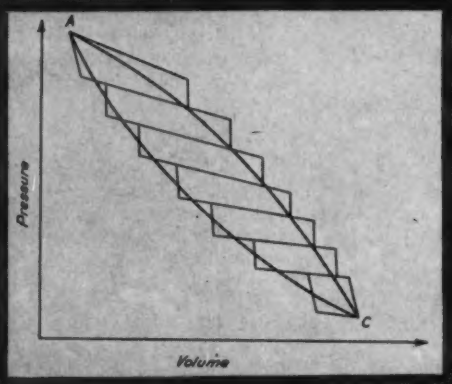


Fig. 2. Pressure-volume diagram illustrating a succession of Carnot cycles.

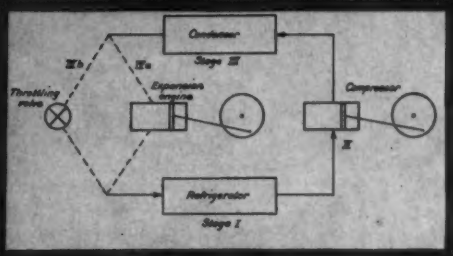


Fig. 3. Vapour-compression refrigeration cycle.

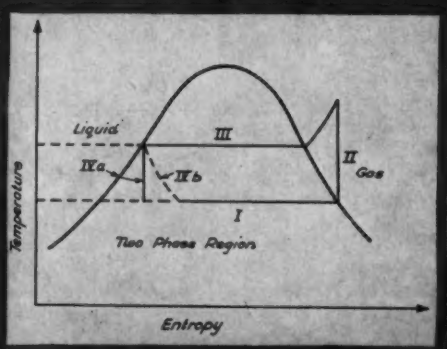


Fig. 4. Entropy-temperature diagram showing the stages of the vapour compression cycle (dry compression).

TABLE I

Process	*Energy Requirements kWh per 1000 cu ft liquid oxygen*	
	Ideal	*Actual*
Reversible work of liquefaction and separation	8.00	(8.02)
Heat exchangers	0.82	(0.98)
Expansion valve	0.09	(0.95)
Expansion engine	Nil	(1.96)
Rectification column	2.65	(4.21)
Motor and compressor	Nil	(17.23)
Heat leaks	Nil	(0.74)
Losses in mixing, air leaks, etc.	0.02	(1.22)
Total	11.58	(35.38)

In the manufacture of liquid oxygen by the Heylandt cycle, in which both forms of expansion can be used, a thermodynamic analysis gives estimates of the power requirements for various stages of the process, and of the possible saving of power by adopting alternative methods. Gardner and Smith[2] have calculated the reversible thermodynamic work for the liquefaction and separation in an ideal case, yielding pure oxygen, and in an actual case where the yield was 99.6% oxygen, from the formula

$$\triangle G = \triangle H - T\triangle S \qquad \ldots . (24)$$

Where $\triangle G$, the Gibbs free energy change, is the reversible work done on the fluid, $\triangle H$ is the enthalpy change, and $\triangle S$ is the entropy change between the initial and final states.

The actual work done, W, is;

$$W = \triangle G + \Sigma T \triangle S_{irr}$$

where $\triangle S_{irr}$ are the irreversible entropy increments in each of the stages: Table I lists the ideal and actual (in parentheses) work for the cycle.

This particular analysis shows that one half of the energy is required by the compression stage, and the greatest saving can be made by improved compressor design, giving more efficient compression. Rectification, which accounts for 12% of the power consumed in the actual cycle, is next in importance. However, here only half the power is recoverable in theory, using an isothermal distillation column, and if an adiabatic column is used the possible saving, even under conditions of minimum reflux, is even less than this. The analysis shows that the method of expansion is only of minor significance.

Throttling, an Example of an Irreversible Flow Process

In the refrigeration cycle described, no attempt was made above to analyse the actual thermodynamic changes taking place in the throttling stage, as this introduces the thermodynamics of an irreversible flow process. A simple example is the production of entropy in a slab situated between two reservoirs at different temperatures, T and $(T + \delta T)$. If the flow of heat from one reservoir to the other is Q, then the entropy change at the first boundary between reservoir and slab is Q/T, and at the second boundary $Q/(T + \delta T)$. The production of entropy for the process is the difference between these two; i.e., $Q\ \delta T(T^2 + T\,\delta T)$. This must be positive, as for an irreversible process in an isolated system there must always be a net production of entropy.

Considering the more complex system, the throttling stage in the refrigeration cycle (Stage IV in Fig. 5), there is conservation of mass (as there is no loss of working fluid), and conservation of energy (as constant enthalpy is assumed for throttling). The entropy production for the stage is the difference between the entropy "flows" into and out of the throttling stage. These can be found from the entropies in Stages III and I, at the beginning and end of Stage IV respectively. By this method the position of the constant enthalpy line can be found on the entropy-temperature diagram. Also if the external heat losses during throttling can be determined calorimetrically, it is possible to find the actual position of the "throttling" stage.

This is just one example of the application of the concepts of irreversible thermodynamics to a flow process. Similar applications are possible whenever there is entropy production in a process which is not carried out reversibly, and the actual energy changes can then be calculated. This technique is or great importance in evaluating rival processes.

REFERENCES
[1] Prigogine, I. "Introduction to Thermodynamics of Irreversible Processes". C. C. Thomas, Ill., and Blackwells, Oxford, 1955.
[2] Gardner, J. B., Smith, K. C. *Proc. of the 1957 Cryogenic Conference*, 1957, p. 32

Adsorption in Industry

THE use of adsorbents for the drying and purifying of gases, the recovery of organic solvents and the separation of closely allied compounds, such as low boiling hydrocarbons, has grown rapidly with the development of new adsorbents and a greater understanding of the mechanisms involved.

Adsorption, however, is still one of the least developed of the unit operations, and has received less attention than its potential utility in certain fields deserves. It is therefore particularly appropriate that the Graduates and Students Section of the Institution of Chemical Engineers should devote one of its symposia to this operation.

The symposium to be held at the Livery Hall, Guildhall, London, on October 20 and 21, is designed to inquire broadly into existing applications of adsorption in industry, and to suggest other applications where adsorption might prove more efficient than existing alternatives, such as absorption or distillation.

The papers to be presented include:

Introduction to Adsorption—J. W. Armond, British Oxygen Research & Development Ltd.

The Design of Industrial Air and Gas Driers—S. Ruhemann, Research and Development Department, A.E.I.-Birlec Ltd.

Industrial Uses of Molecular Sieves—J. F. Edwards, Union Carbide Ltd.

Design and Performance of a Fluid Bed Cs_2 Recovery Plant—M. J. Hagger, British Celanese Ltd.

Chromatography for Process Control. The Design of a Laboratory Analyser for Use in the Petroleum Industry—C. P. Williamson, British Petroleum (Kent) Ltd.

Adsorption by Active Carbon of Solvents in the Liquid Phase—A. Bryan, Solvent Recovery Section, Sutcliffe, Speakman & Co. Ltd.

The Use of Activated Charcoal in the Treatment of Trade Wastes—D. H. Sharp, Fisons Ltd.

The symposium chairman will be E. S. Sellers, now manager of the Petroleum Division, B.P. Research Centre. Registration will commence at 9.15 a.m. on October 20, and fuller details may be obtained on application to M. E. Banfield, Graduates and Students Section Committee, 16 Belgrave Square, London, S.W.1.

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PART I

SOME CONSIDERATIONS OF DENSE-PHASE FLUIDISED BED CORRELATIONS

Worked examples illustrate the use of correlations for calculating the onset of fluidisation and bed expansion

by MAX LEVA*

FLUIDISATION as we know it today is a development of barely twenty years. Nevertheless, the contributions have been of greatly diversified character and their rate has been prolific. Hence it is felt that a service will be rendered by giving a brief review and critical consideration of some of the major correlations that pertain to the dense-phase fluidised state. The nature of the correlations, data required for their use and limitations will be presented. Furthermore, attention will be directed to some of the problems that still await solution.

This first paper deals with some correlations that have a bearing on the mechanics of the dense-phase fluidised state, whereas in the follow-up article questions pertaining to heat and mass transfer will be considered.

The most important questions to the engineer concerned with design pertain to:

(1) evaluation of the minimum fluid rate for fluidisation;
(2) prediction of the height of the fluidised column when acted upon by a definite fluid rate; and
(3) estimation of possible solids carry-over.

In addition to these points, indications pertaining to anticipated fluidisation performance will, of course, also be of importance. In the following consideration will be given to these few questions.

Symbols Used

D_p = particle diameter;
d_p = diameter of one size component of particles in a mixture of particles;
f = function of;
G = fluidisation mass velocity;
G_{mf} = fluidisation mass velocity at onset of fluidisation (minimum fluidisation);
g_c = conversion factor;
n = exponent in Richardson and Zaki expressions;
Re = abbreviation for $\frac{D_p G}{\mu}$;
ϵ = bed voidage;
ϵ_{mf} = bed voidage at minimum fluidisation;
μ = fluid viscosity;
ρ_F = fluid density;
ρ_S = solids density (*not* bulk density); and
φ_S = particle sphericity (shape factor).

Correlation for Predicting the Onset of Fluidisation

Of all the available correlations, the one for predicting onset of fluidisation is probably the most reliable and best supported. This is so because flow through an incipiently fluidising bed does not seem to differ greatly from flow at somewhat lower fluid mass velocity through a fixed bed of the same particles. In fact, the onset of fluidisation for many shapes of particles follows quite smoothly as the bed is subjected to a certain flow rate. Upon reducing the flow rate nominally the fixed bed results again. Hence there is for certain types of particles virtually a dynamic equilibrium at the point of initial or minimum fluidisation. In view of this situation, it is only logical to combine a well-established analytical expression for pressure drop through a fixed bed with the buoyant weight of the bed and thereby obtain a suitable working correlation. Thus the minimum fluid mass velocity for fluidisation is given by[5]

$$G_{mf} = \frac{0.005\ D_p^2\ g_c\ \rho_F\ (\rho_S - \rho_F)\ \varphi_S^2\ \epsilon_{mf}^3}{\mu\ (1 - \epsilon_{mf})} \quad \ldots . (1)$$

A considerable simplification of this correlation resulted from the discovery that

$$\frac{\varphi_S^2\ \epsilon_{mf}^3}{(1 - \epsilon_{mf})} = f\left(\frac{D_p\ G}{\mu}\right) \quad \ldots . (2)$$

Thereby a specific knowledge of the minimum fluid voidage of the particles and particle sphericity is obviated. Since these quantities are moreover only infrequently avail-

* Consulting Chemical Engineer, 808 Beaver Avenue, Pittsburgh, 33, Pennsylvania, U.S.A. He is widely known as an authority on fluidisation and has published a number of important works in this field, the most recent being *Fluidisation* (McGraw-Hill Co.).

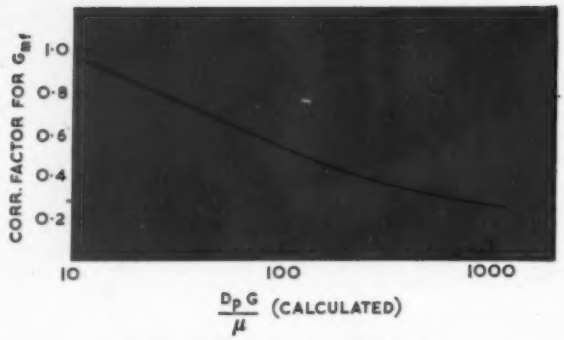

Fig. 1. Correction factor for G_{mf}.

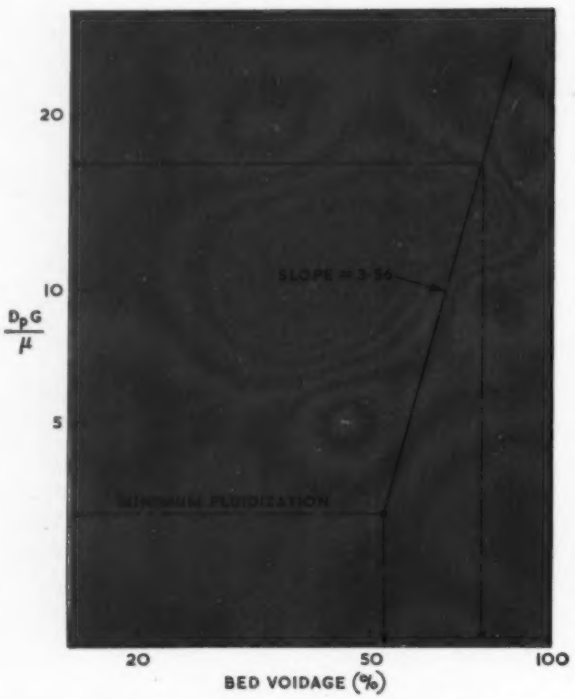

Fig. 2. Evaluation of expanded bed voidage by method of Richardson and Zaki.[11]

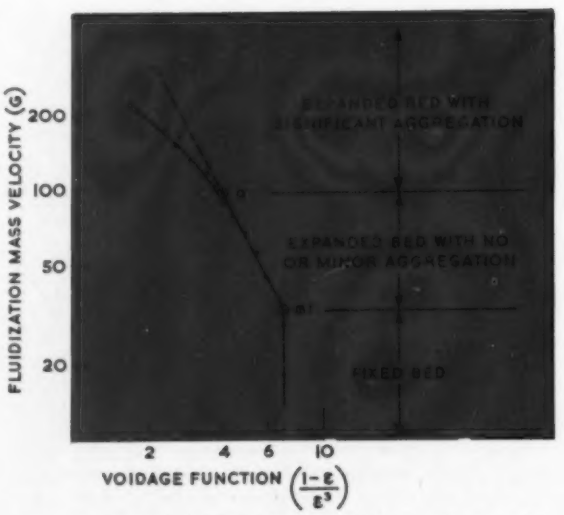

Fig. 3. Typical gas-solid expansion data; silica sand of $D_p = 0.00632$ in. fluidised by CO_2.

able in process specifications, the resulting correlation is of much greater usefulness.

Incorporating this relationship, developed elsewhere,[6] selecting a combination of frequently used units and including the conversion factor, g_c, in the proportionality constant resulted in

$$G_{mf} = 688\ D_p^{1.82}\ \frac{[\rho_F\ (\rho_S - \rho_F)]^{0.94}}{\mu^{0.88}} \qquad \ldots.(3)$$

The mass velocity for minimum fluidisation, G_{mf}, will be in lb/hr, sq ft if particle diameter D_p is expressed in inches, fluid viscosity in centipoises and fluid and solids densities, ρ_F and ρ_S, in lb/cu ft.

With solids which are not vesicular, that is with no appreciable internal porosity accessible to fluid flow, solids density may be obtained by pycnometer. However, with vesicular materials this may lead to substantial inaccuracies. It is then suggested that solids density be evaluated by the method of Ergun.[3]

As given, the correlation will apply only as long as $\frac{D_p G}{\mu} < 10$. It may, however, be extended far into the turbulent range by applying the correction factor given in Fig. 1. Thus in using the correlation it is recommended that $\frac{D_p G_{mf}}{\mu}$ be evaluated, and if in excess of 10 the correction factor obtained from Fig. 1 is to be applied to the calculated value of G_{mf}.

The range of variables underlying the data supporting Equation (3) is given below:

Particle diameter, D_p	...	...	0.205-0.0020 in.
Particle sphericity, φ_S	...	...	1.00-0.60 (approx.)
Solids density, ρ_S ...	...	...	673-62 lb/cu ft
Fluid density, ρ_F ...	...	...	62.3-0.005 lb/cu ft
Fluid viscosity, μ ...	...	...	1.0-0.001 centipoise
Column diameter, D_t	...	...	6.0-0.4 in.

Most solids beds referred to above were composed of narrow solids cuts. Only relatively few observations were reported for wider size distributions.[5, 7, 8] The data of Katz[4] cover essentially two-component systems with sizes far apart from each other, whereas the other few studies pertain to a more continuous spectrum of sizes. Reboux[11] has shown that calculation of the composite diameter of a mixture of sizes according to

$$D_p = \frac{1}{\sum \frac{X}{d_p}} \qquad \ldots.(4)$$

is in agreement with the concept of hydraulic radius in packed beds.

Equation (3) is based wholly on beds composed of materials of the same solids density. In actual practice, beds may occasionally contain relatively large fractions of materials of different densities. Only a few isolated data have been published on the fluidisation of mixed materials.[7] Their behaviour at the onset of fluidisation does apparently resemble the phenomenon observed with two widely differing sizes in the bed, as investigated by Katz.[4] Hence there is to be expected a range of flow rates for which such beds, composed of different materials, will become wholly fluidised. Virtually no data of this sort have been obtained.

Practically all the data underlying Equation (3) were observed with perforated-plate bed supports or related structures. It is well known that design of the fluid inlet device has an effect on fluidisation, and, of course, on G_{mf}. Thus with conical inlet devices depending on the apex angle, fluidisation may not even result, but instead there may be spouting, as described by Mathur and Gishler.[9] Spouting, a more recent method of solids-fluid contacting, is in a sense related to channelling, in so far as in both instances fluid distribution over the vessel cross-section is not uniform.

Regarding effect of fluid inlet device on the onset of fluidisation no systematic data have so far been reported.

For materials that will fluidise readily, Equation (3) will tend to give high values of G_{mf}. However, for solids with moderate channelling tendencies the values predicted by the correlation should agree closely with experimental data. For materials with severe channelling tendencies there is so far, of course, no correlation that will predict the onset of fluidisation, if such can be had at all. This is so because no systematic study of the causes of solids channelling has been made. The situation is even worse, since not even a useful index for describing channelling intensity has so far been proposed. A few ideas based on pressure drop in beds with channelling tendencies have been advanced[1, 7] which may eventually prove helpful.

Correlations for Bed Expansion

A. Liquid-fluidised Systems

It has been shown that the expansion behaviour of liquid-fluidised solids may be described by a flow equation of the type proposed by Carman[2] up to a bed voidage of about 80%.[5] For flows causing higher voidages, correlations of this kind will predict a lesser expansion than is actually obtained. Failure to apply to greatly expanded beds is due to the fact that modified channel flow, a prerequisite for the validity of Carman-type flow equations, can no longer be assumed in solids beds with greatly expanded inter-particle spaces.

The correlations of Richardson and Zaki,[11] specifically valid for liquid-fluidised beds, are recommended, since they virtually cover the entire expansion range of solids beds. In their original correlation they chose to relate the ratio u_f/u_t to bed voidage. They found that

$$\frac{u_f}{u_t} \propto \varepsilon^n \qquad \ldots.(5)$$

where n is chiefly dependent on flow range, as expressed by the modified Reynolds number, and shown below:

$$n = \left(4.35 + 17.5\,\frac{D_p}{D_t}\right) \mathrm{Re}^{-0.03} \text{ for } 0.2 < \mathrm{Re} < 1.0 \qquad \ldots.(6)$$

$$n = \left(4.35 + 18\,\frac{D_p}{D_t}\right) \mathrm{Re}^{-0.1} \text{ for } 1 < \mathrm{Re} < 200 \qquad \ldots.(7)$$

$$n = 4.45\,\mathrm{Re}^{-0.1} \text{ for } 200 < \mathrm{Re} < 500 \qquad \ldots.(8)$$

$$n = 2.39 \text{ for } \mathrm{Re} > 500 \qquad \ldots.(9)$$

These correlations apply, of course, only to beds composed of a relatively narrow size range. With beds of an appreciable size spectrum size classification will set in, which must be expected to modify these correlations. Most studies that pertain to size classification in liquid-fluidised columns were made really without regard to fluidisation as such, and are found in the realm of water filtration through rapid sand filters. The calculation procedures for such systems is much more involved than the simple procedure for narrow cuts discussed here.

For calculating the expanded height of a narrow cut solids bed when under a certain liquid flow rate, it is more convenient to relate in the Richardson and Zaki method either mass velocity alone or the modified Reynolds number to voidage, rather than the velocity ratio as proposed in Equation (5). This is illustrated below:

Example. High boiling hydrocarbon synthesis constituents are to be removed from a hydrocarbon synthesis catalyst by contacting the catalyst with a stream of octane. In order to have a loose bed and good contact, it is proposed to pass the octane *up* the column and thereby fluidise the bed. For the conditions given below, estimate the height of the dissolving chamber so that no catalyst will be lost. The operation takes place at 80°F.

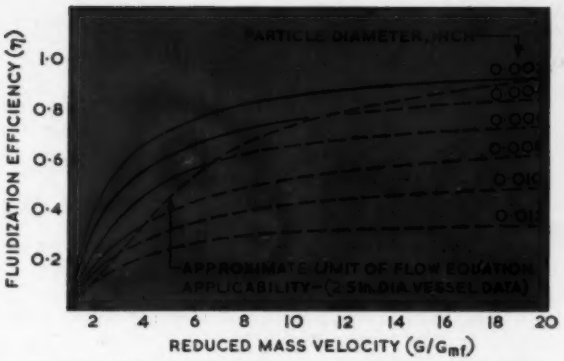

Fig. 4. Fluidisation efficiency versus reduced mass velocity.

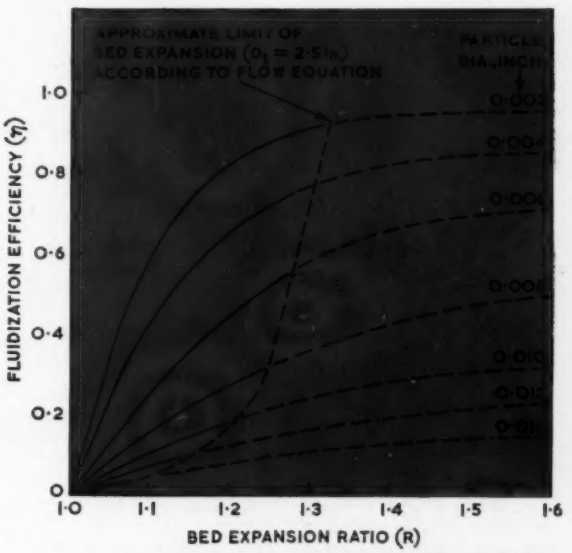

Fig. 5. Fluidisation efficiency versus expansion ratio.

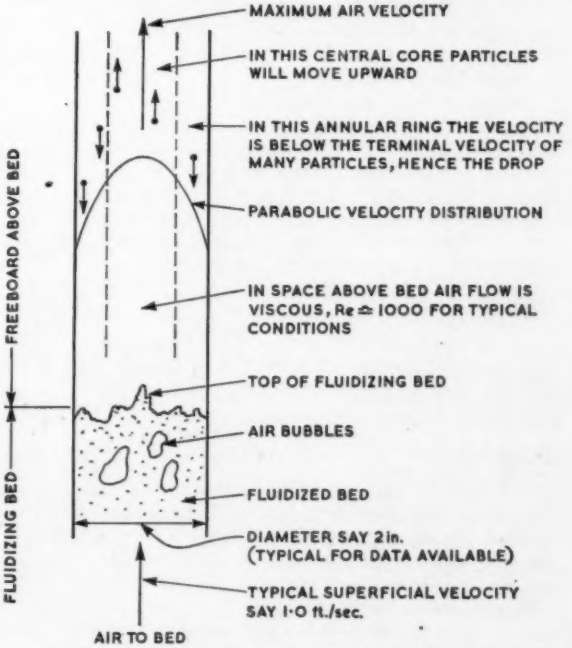
MAXIMUM AIR VELOCITY
IN THIS CENTRAL CORE PARTICLES WILL MOVE UPWARD
IN THIS ANNULAR RING THE VELOCITY IS BELOW THE TERMINAL VELOCITY OF MANY PARTICLES, HENCE THE DROP
PARABOLIC VELOCITY DISTRIBUTION
IN SPACE ABOVE BED AIR FLOW IS VISCOUS, Re ≏ 1000 FOR TYPICAL CONDITIONS
TOP OF FLUIDIZING BED
AIR BUBBLES
FLUIDIZED BED
DIAMETER SAY 2 in. (TYPICAL FOR DATA AVAILABLE)
TYPICAL SUPERFICIAL VELOCITY SAY 1·0 ft./sec.
FREEBOARD ABOVE BED
FLUIDIZING BED
AIR TO BED

Fig. 6. Typical air velocity and tube diameter met in elutriation studies and resulting undesirable velocity pattern in freeboard.

Particle size, D_p	0.0150 in.
Solids density, ρ_s (neglect effect of adhering hydrocarbons)	312 lb/cu ft
Liquid density, ρ_F	44 lb/cu ft
Liquid viscosity, μ	0.5 centipoise

Twenty-five pounds of the catalyst are thus to be treated in a 6-in. diameter column, and the dry bed voidage is 52%. The upward velocity of the octane will be 0.10 ft/sec.

Solution. First we shall evaluate the minimum fluidisation mass velocity. This value, together with the given bed voidage, will be the anchor point for the Richardson and Zaki line, the slope of which will be evaluated from the proper correlation. Extending the simple graphical layout to the proper mass velocity will then give the resulting bed voidage and hence column height.

Equation (3) is applied directly; thus

$$G_{mf} = 688 \times 0.0150^{1.82} \frac{\{44\ (312 - 44)\}^{0.94}}{0.5^{0.88}}$$

$$= 4070 \text{ lb./hr, sq. ft.}$$

$\frac{D_p\ G_{mf}}{\mu} = \frac{0.015 \times 4070}{12 \times 0.5 \times 2.42} = 4.21$, hence no correction is required.

For the specified octane flow the Reynolds number will become

$$\frac{D_p\ G}{\mu} = \frac{0.015 \times 0.10 \times 3600 \times 44}{12 \times 0.5 \times 2.42} = 16.4$$

The average Reynolds number is 10.3 and according to Equation (7)

$$n = \left(4.45 + 18 \cdot \frac{0.0150}{6.0}\right) \times 10.3^{-0.1} = 3.56$$

From Fig. 2 the expanded bed voidage is then found to be 77%.

The original unexpanded bed volume was $\frac{25}{312\ (1 - 0.52)}$ = 0.167 cu. ft, and the expanded volume will be

$$\frac{25}{312\ (1 - 0.77)} = 0.348 \text{ cu. ft.}$$

With a bed cross-section of 0.197 sq ft this corresponds to an initial bed height of $\frac{0.167}{0.197} = 0.85$ ft and an expanded bed height of 1.77 ft.

B. Gas-fluidised Systems

Whereas it has been found that flow through liquid-fluidised beds may up to a point be analysed by a Carman-type equation, flow through gas-fluidised beds shows significant deviation from this correlation, even at flow rates which are only little in excess of G_{mf}.

The deviations from the Carman flow equation have been carefully noted[5] and indications are that there are the following two major causes for the deviation:

(1) the movement of the particles inside the bed; and
(2) the solids aggregation, which manifests itself in gas-solid systems.

It has been shown that a convenient test of whether the Carman flow equation applies[5] merely demands that on logarithmic co-ordinates the fluidised bed mass velocity is related to the bed voidage function $\frac{1 - \varepsilon}{\varepsilon^3}$. If the data follow the Carman correlation, a plot of slope $m = -1.0$ must result. Extensive data analyses indicate that the movement of the particles will cause the slope to become *more* negative, whereas the tendency towards solids aggregation has the *opposite* effect.[5] Hence it is possible to have the two agencies at work to such an extent that a slope $m = -1.0$ will result for some specific conditions, thus giving the impression as though the system would behave in accord with the Carman flow equation. Such conditions appear to prevail more or less when solids of about 0.015 to 0.020 in. are fluidised with a gas. For this particle size range, the effects of particle movement will approximately offset the effect of aggregation, and, moreover, this seems to be the case virtually for almost the entire flow range under which beds of such particle size are normally operated. Although for smaller particles the two agencies are active as well, it is fortunate that for these particle sizes their main effects do not show up in the same flow interval. Thus particle movement effects are chiefly indicated in the lower flow region, whereas aggregation becomes more pronounced at elevated flow rates. Hence it is possible to recognise individual effects and thereby interpret more intelligently gas-solid expansion data.

Some typical data showing these effects plainly are given in Fig. 3. The data pertain to a silica sand of $D_p = 0.00632$ in., fluidised with CO_2 in a 2½-in.-diameter tube. Up to point "mf" there is no fluidisation. From point "mf" to point "a" there is fluidisation and the slope is constant at −1.95, indicating a considerable deviation from −1.0 and hence indicating pronounced particle movement. At point "a" aggregation becomes sufficiently pronounced so that the slope begins now to deviate from −1.95 and becomes progressively less negative. As this proceeds, slugging manifests itself more and more. It is conceivable that this deviation in slope beyond point "a" may be used to define an index that should permit a more quantitative and fundamental definition of aggregation and slugging than has so far been achieved.

The portion of all the data for which the region of "mf" to "a" may be represented by a satisfactory straight line (and let it be said that the vast majority of data conform to this) have been used to define the fluidisation efficiency term, and develop a generalised expansion behaviour of gas-fluidised beds.[5] These correlations are given in Figs. 4 and 5. For evaluating these parameters a knowledge of the reduced gas mass velocity is required. The reduced gas mass velocity is merely the ratio of the fluidisation gas mass velocity and G_{mf}, as calculated from Equation (3).

The experimental limits of these correlations are, of course, noteworthy and this has been discussed in detail elsewhere.[5] As the gas mass velocity is increased beyond the unstable region that may be termed the slugging range, the dense-phase bed transforms into the dilute phase. This transition region does also prevail in liquid-fluidised beds, with the difference, however, that with liquids slugging does only very infrequently occur. Since this region in the liquid-fluidised bed is not of the same instability as the corresponding region in the gas-fluidised bed, a study of this zone in the liquid-fluidised system will be of little value as far as a better understanding of this region in gas-fluidised systems is concerned.

The method of analysis outlined for evaluation of expanded height in gas-fluidised beds seems so far to be the only available tool for estimating gas-solid bed expansion behaviour. Although it is based on performance in small-scale columns, its use and extension to considerably larger units have given gratifying results. Of course, additional substantiations would be desirable, especially with equipment of many feet diameter and for various gas inlet devices.

Elutriation by Gas Streams

With solids beds composed of a range of sizes, carry-over of fines may set in at gas rates that are well in the conventional operating range. Carry-over, or elutriation, as the phenomenon is also called, is, of course, of importance in many fluid bed designs, as it is usually not permissible for various reasons to allow solids fines to leave the system.

Hence an understanding of the laws that govern elutriation is most desirable.

Unfortunately, relatively few data have so far become available, which must serve as basis for correlation. These various sources pertaining exclusively to small-scale equipment have been reported elsewhere.[5] The findings have revealed that for certain fines concentration ranges a so-called elutriation velocity constant may be defined. Moreover, data have become available which indicate fairly accurately how the elutriation velocity constant is dependent on solids properties and also to some extent on bed height. The indications are that the mechanism by which fines elutriation from a bed of solids occurs is rather complex. Thus it appears that before elutriation from the top of the bed can occur a fines concentration gradient must be first established through the bed, such that there will be a substantial enrichment of fines in the top layer. Thus it is apparent that the problems attending elutriation are connected with the stratification or size classification problem, for which virtually no co-ordinated investigations have so far been undertaken. This very brief indication of mechanism is mentioned here merely for the purpose of pointing out a few of the fundamental problems that still require attention, problems which are inherently interrelated.

As a final consideration be it mentioned that a perhaps more than ordinary effect of chamber diameter as well as freeboard above the bed has been noted to influence elutriation rates. Frequently, the effects observed have been contradictory, which might well indicate that the cause for the lack of agreement could be a rather specific condition, in itself being at variance with the chamber diameter.

Thus upon examination of the bulk of the elutriation data it is noted that with the small-diameter equipment on hand and the prevailing range of gas mass velocities chosen the fluid moving up the empty section of the column is generally in the laminar flow range and only in some instances, where large particles are to be elutriated, may the fluid be in the early turbulent flow region. However, for a fluid in laminar flow the velocity profile is parabolic, with the average velocity being one-half of the central maximum velocity. Moreover, near the wall the velocity will reduce to very low values indeed. All this is indicated in Fig. 6 and it is quite conceivable that solids, once entrained away from the bed under the influence of the average velocity, will proceed very much faster upward, when shifted toward the centre. If then for some reason the solid particles move "out of line" and drift toward the perimeter, the fluid velocity may then well be sufficiently low so that the particles must now return to the bed. Such a circulation pattern would, of course, greatly affect the reproducibility and consistency of the data. It is also readily seen that thereby the effect of freeboard would be made to appear much more enigmatic than it actually may be.

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* Consulting chemical engineer, Leva Engineering Research Laboratory, 808 Beaver Avenue, Pittsburgh, 33. Pennsylvania.

New York Conference of the American Chemical Society

THE American Chemical Society's 138th National Meeting just concluded in New York attracted an attendance of no less than 16,000. Among the 240 or more papers which were arranged into various symposia were a number with a distinct chemical engineering content.

The symposium subjects included Safety in Chemical Plants, and Capital Investment and its Control. In the first group H. L. Volz dealt with some of the problems of plants manufacturing propellent fuels. In any case the scale-up of any chemical process demands a careful assessment of safety factors, but when the product is a high energy propellent the design problems related to safety are very much more acute. The author stresses the need for a comprehensive assembly of all the available information relating to toxicity, flammability, explosion hazard and so on, as a preliminary to designing and operating a safe plant.

Another paper in the safety symposium dealt with the hazards of handling powerful oxidisers such as fluorine and chlorine fluoride. This paper, given by H. A. Volz, gave design requirements for bulk handling and manufacturing equipment. Part of the paper deals with plant location, its barricading, valving arrangements, materials of construction, ventilation, waste disposal and emergency disposal, in addition to describing in detail various safety devices.

A further paper (J. S. Snyder) approached the problem of how to evaluate the magnitude of a hazard in the manufacture of a chemical and how to determine the conditions for operating its plant safely.

Finally, a paper made timely through some recent incidents caused by isopropylether peroxide deals with the stabilisation of ethers against peroxide formation.

The purpose of the symposium on capital investment was to explore the various principles and methods employed in the chemical industry to control investments. A number of representatives from chemical industry outlined their experiences in this group of papers, the companies involved including Chemstrand, Union Carbide and Foster Grant.

Studies of process dynamics and of diffusional operations were the subjects of other papers presented at this meeting and a few new designs of processing equipment also emerged.

One paper was concerned with the comparison of theory and experiment in relation to the transient behaviour of batch thermogravitational thermal diffusion columns without reservoirs. Another described an investigation of the dynamic characteristics and controllability of pulse columns by means of the I.B.M. 650 digital computer. One of the features of this paper was the technique used to solve two sets of different—differential material balance equations which made possible the evaluation of the effects of design, operating and extraction system variables upon column dynamics and controllability.

Of considerable interest from a theoretical angle was the paper given by Chen-Jung Huang *et al.* on mass transfer in agitated vessels. The authors extended the film penetration concept to the problem of mass-transfer with chemical reaction and found that qualitatively both the Hatta film theory and Danckwert's surface renewal theory are in fair agreement with experimental results.

Of the remaining papers one in particular deserves detailed mention; it dealt with epoxidation as a unit process and described the chemistry of epoxidation and its application in chemical manufacture. At the same time, recommendations were given for equipment design along with a process flow diagram.

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PREDICTION OF REFRIGERANT SIDE HEAT TRANSFER

The lack of knowledge of the effect of variables affecting the boiling film conductance makes its prediction uncertain in scraped-surface heat exchangers

by A. H. P. SKELLAND,* Ph.D., B.Sc., A.R.I.C., A.M.I.Chem.E., A.F.Inst.Pet.

DOUBLE-pipe, scraped-surface heat exchangers are widely used in the food, chemical and allied industries, yet few data on heat transfer in such equipment have appeared in the literature.

The author has recently been concerned with attempts to develop a correlation for the scraped-film coefficient of heat transfer, h_s, in this device. In refrigerant-jacketed Exchangers h_s is related to the overall coefficient, U, by the general equation:

$$\frac{1}{U}=\frac{1}{h_r}+\frac{1}{h_m}+\frac{1}{h_s}$$

where h_m is the usual metal wall coefficient, given by dividing the thermal conductivity by the metal thickness and h_r is the refrigerant-film heat-transfer coefficient.

Quantitative prediction of h_r is clearly necessary either for estimation of U in existing or future equipment or for calculation of h_s from experimentally determined values of U.

This paper is intended to draw attention to the difficulties associated with the quantitative prediction of h_r.

Selection of the Prevailing Mechanism of Heat Transfer in the Refrigerant

Attempts to calculate h_r either by assuming a forced convection mechanism and using the usual Dittus-Boelter equation, or by assuming a natural convection mechanism and using the usual correlation involving Nusselt, Grashof and Prandtl number, lead to improbably low values of the refrigerant film coefficient. (In some cases less than experimentally determined values of U—an impossible result.)

It is evident, therefore, that some type of boiling mechanism must be prevailing in the refrigerant to give higher rates of heat transfer. The boiling curve of Farber and Scorah[3] is shown with additional comments in Fig. 1 to illustrate the several different boiling mechanisms which are known to exist.

Brown and Marco[11] state that "Heat transfer to boiling liquids occurs in ... the evaporators of refrigerating plants. ...

"Boiling in the ordinary range of temperatures is termed nucleate boiling because of the mechanism by which it takes place. ..."

It is shown below, however, that an assumption of nucleate boiling may sometimes be invalid.

Symbols Used

C_L = specific heat of liquid phase;
D = characteristic dimension of heating surface (e.g., tube diameter);
h_m = metal wall coefficient of heat transfer;
h_r = refrigerant film coefficient of heat transfer;
h_s = scraped film coefficient of heat transfer;
k_L = thermal conductivity of liquid phase;
U = overall coefficient of heat transfer;
ΔT = temperature difference between heating surface and bulk of boiling liquid;
μ_L = viscocity of liquid phase;
μ_{L_a} = μ_L at the normal boiling point under atmospheric pressure;
σ = surface tension; and
σ_a = σ at the normal boiling point under atmospheric pressure.

Selection of a Correlation for h_r

Even if one decides upon a nucleate boiling mechanism, more than nine different and contradictory correlations are available in the literature which claim to apply to this process. This is illustrated in Table I, which compares the exponents indicated by some of these correlations on components of the liquid Prandtl group and some of the other variables.

Westwater[4] commented on the last five correlations mentioned in Table I as follows:

"These five non-theoretical correlations are sufficient to show the difficulty of selecting a satisfactory empirical correlation. The various authors do not agree on the quantitative effects of such important variables as the temperature difference and surface tension; they fail even to agree on the qualitative effects of variables such as the liquid viscosity. ..." Similar considerations must have led Coulson and Richardson[2] to state: "It must at present be accepted that there are no satisfactory relations for determining film coefficients for boiling liquids. ..."

* Dr. Skelland is Assistant Professor of Chemical Engineering at the Illinois Institute of Technology, Chicago, U.S.A.

TABLE I—Comparison between Exponents on Certain Variables as Indicated by Some of the Available Correlations for Nucleate Boiling. Not all Relevant Variables are Included Here.

Authors	Ref.	Type of Correlation	k_L	C_L	μ_L	$\mu_L a$	σ	σa	ΔT	D
Rohsenow	4	semi-theoretical	5.1	−2.1	−4.1	—	−0.5	—	2.0	0
Forster and Zuber	4	semi-theoretical	0.79	0.45	−0.29	—	−0.5	—	0.24	0
McNelly	5	empirical	1.0	2.23	0.0	—	−1.0	—	2.23	0
Gilmour	12	empirical	0.6	0.4	−.03	—	−0.425	—	—	−1.0
Cryder and Gilliland	4	empirical	2.97	0.43	−3.45	—	−1.65	—	2.39	2.1
Cryder and Finalborgo	4	empirical	—	—	—	—	—	—	2.5	—
Jakob and Linke	4	empirical	5.0	—	—	—	−2.5	—	4.0	0
Jakob (from Insinger and Bliss)	4	empirical	1.6	1.6	—	—	−1.6	—	2.1	0
Bonilla and Perry	4	empirical	1.85	1.85	−1.85	3.7	0.85	−2.7	2.7	—

Effects Not Allowed for in Correlation for h_r

When nucleate boiling occurs on the surface of a hot metal the following factors—which are not allowed for in any of the available correlations—are also found to exert a drastic influence on the size of the film coefficient:

(1) type of metal,[6, 12]
(2) degree of tarnishing of the surface,[6, 7, 11] and
(3) degree of roughness of the surface.[6]

References 6, 7 and 11 show the effects of each of these three factors on the boiling film coefficient to be in some cases over 200%.

Effects Due to Contamination of the Refrigerant

It has been found that, in the particular laboratory- and full-scale equipment used in one of the author's previous papers,[1] a film of lubricating oil was progressively coating the surface of the tubes adjacent to the liquid refrigerant (ammonia). It seems that this oil was carried over from the ammonia compressor, despite the use of oil traps.

While this oil film constitutes an added resistance to heat transfer, it may also have a further serious effect in modifying the actual mechanism of boiling. Thus Rhodes and Bridges[9] showed that a very thin film of mineral lubricating oil may inhibit nucleate boiling on the surface of a steel tube and induce either transition or film boiling instead (regions 4 and 5, Fig. 1), with serious reduction in the film coefficient.

Conclusions

(1) It is evident from these observations that considerable uncertainty may exist concerning the accuracy of any estimated refrigerant film coefficients of heat transfer in this sort of equipment.
(2) In experimental studies of the scraped-film coefficient, greater accuracy should result from the use of a water-jacketed exchanger as in the work of Houlton[10] and of Skelland, Oliver and Tooke.[2] This will enable closer estimation of the jacket-side film coefficient, though care must be taken to ensure that the flow régime in the jacket is appropriate to the correlation used. Thus for a rectangular-section, helical water jacket of the dimensions used in Houlton's work, his results suggest that turbulence was not established in the jacket (and the Dittus-Boelter equation therefore not applicable) until a Reynolds number of 25,500 was exceeded.
(3) A rough tube surface adjacent to the refrigerant will give higher nucleate boiling heat transfer than a smooth surface.
(4) The type of metal from which the tube surface is made will have a substantial effect on heat transfer by nucleate boiling.
(5) Tarnishing and corrosion of the surface may either increase or decrease heat transfer by nucleate boiling.
(6) The presence of a very thin film of oil on the surface—perhaps carried over from the refrigerant compressor—may change the basic mechanism of boiling, with serious reduction in heat transfer. This effect is separate from the added thermal resistance of the oil film itself.

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Industry Widely Represented at Effluent Exhibition

REPRESENTATIVES of many industries will attend the first Effluent and Water Treatment Exhibition and Convention to be held from October 18 to 21 at the Seymour Hall, London, judging from early figures of registrations.

The papers to be presented deal with a variety of methods of treating and controlling trade wastes, and cover many aspects of the pollution of river and coastal waters, and practical aspects such as pumping, plant design, water softening and marine water treatment will receive attention.

Industries represented by delegates include: paper and board, brewing, oil and petroleum, leather, aircraft, industrial finishing, government and local government, coke, agriculture and poultry, food, iron and steel, coal, atomic energy, synthetic detergents, sewage and water treatment, laundries, plastics and gas.

The authors and others who are expected to attend include many holding positions of considerable responsibility in industry such as senior research officers, consultants, chief chemists, city engineers, trade effluent officers, laboratory managers, river inspectors, sewage disposal chemists, directors of research, waterworks engineers, civil engineers, chief analysts, sewage works managers, borough clerks, works managers, etc.

Delegates have also registered from overseas countries including Holland, South Africa, Rhodesia, Germany, Australia and Canada.

RADIOACTIVE TRACING OF PHENOL LOSSES IN OIL REFINING

An investigation carried out at the Fawley Refinery which revealed the sources of losses of an expensive chemical

by R. E. PEGG, B.Sc., Ph.D., M. F. HOARE, B.A., B.Sc., D.Phil., J. L. BETON, B.Sc., Ph.D., G. B. COOK, B.Sc., Ph.D., and H. E. DOBBS, B.Sc.*

LOSSES in any plant, whatever the process, are always of concern to the chemical engineer. This is true, for instance, in the manufacture of lubricating oils, where solvent extraction is used to remove undesirable components such as aromatic compounds, thereby raising the viscosity index and improving the colour and oxidation stability of the product. Thorough recovery of solvent reduces make-up costs and refinery engineers take considerable pains to locate and minimise losses.

At many refineries, phenol is the solvent used for refining lubricating oils. A typical plant (Fig. 1) consists of a multi-plate counter-current extraction tower, and solvent recovery sections in which the phenol is recovered by distillation and by steam distillation from the two phases into which the system partitions itself. The purified oil (known as the raffinate) is passed on for further treatment, while the extracted material, after the phenol has been distilled off, is fed to other refinery units. Phenol from both dry recovery sections passes to a common storage tank, from which it is recirculated; the steam distilled phenol passes from its own subsidiary storage tank through a drier before rejoining the main phenol bulk. The major part (65-80%) of the phenol leaves the extraction tower in the extract phase, the raffinate phase containing only 8-12% of phenol before distillation.

A close check is kept on the phenol contents of all streams leaving the plant, so that a solvent balance can be drawn up and a careful watch kept on make-up demand. In this way, it was found at the Fawley refinery that 0.5 tons per day of phenol were required for make-up in a total inventory of 200 tons. Of this, about 0.15 tons could be attributed to mechanical leakage and similar losses concomitant with operation on a large scale, and a further 0.15 tons could be accounted for by residual phenol in the extracted material. But as no really satisfactory explanation could be found for the loss of the remaining 0.2 tons of phenol, it was decided

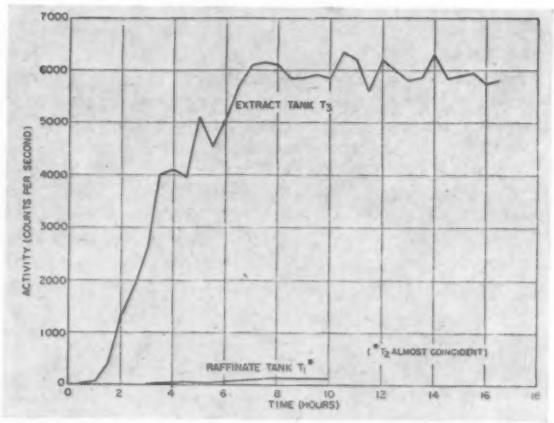

Fig. 1. Typical phenol extraction plant.

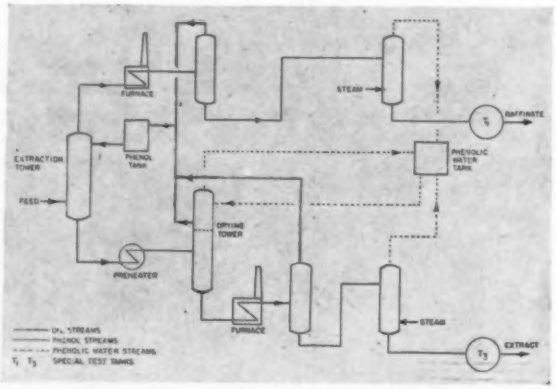

Fig. 2. Radioactivity in test tanks during plant experiment.

* Dr. Pegg and Dr. Hoare work for Esso Research Ltd. at Abingdon; Mr. Dobbs, formerly of the Wellcome Research Laboratories, is now at the Isotope Division of the U.K.A.E.A.; Dr. Beton, formerly of the Isotope Division of the U.K.A.E.A., is now at the Patents Department of I.C.I. Ltd.; and Dr. Cook, head of the Chemistry Group of the Isotope Division at Harwell, is now mainly occupied at the International Atomic Energy Agency's Laboratories near Vienna.

to make a thorough investigation of the ways in which phenol might be lost from the plant.

Review of Methods

The final phenol content for streams leaving the plant had been set at 0.005%, determined by conventional cold caustic soda extraction of samples taken periodically from the plant. The plant operators felt that a possible cause of the losses could be ascribed to occasional surges of phenol which were being missed by the analytical checks. To examine this hypothesis it was clearly desirable to monitor the phenol contents of exit streams continuously, and so methods of automatically carrying out the analyses on the plant itself were considered. Ultra-violet absorption methods were ruled out, since the absorption due to phenol, especially at low concentrations, would be masked by absorption of other compounds present in the oil. In order to use this procedure, it would therefore be necessary to carry out (automatically) extraction with caustic alkali, acidification to liberate phenol, and measurement of the absorption of the resulting solution. A simpler approach would be to use an infra-red analyser, measuring the absorption due to the organic hydroxyl group, but water and other impurities would interfere seriously. Furthermore, to give adequate plant coverage it would be necessary to use a number of such analysers, the development and installation of which would be prohibitively slow and expensive.

Since such analytical methods seemed to be impractical, consideration was given to a radiotracer method. Counting equipment was readily available if the phenol could be made suitably radioactive. However, phenol consists of carbon, hydrogen and oxygen, and continuous radioactive tracing seemed impossible since the only practical radioactive isotopes, carbon-14 and tritium, are beta-emitting isotopes giving radiation which will not penetrate the steel walls of the plant. The possibility of using a substituted phenol as a tracer for the phenol itself was therefore proposed; the separation processes used on the plant—solvent extraction and distillation—are not severe, and it was considered that a carefully chosen substituted phenol should follow phenol reasonably well. To be satisfactory, the substituted phenol should emit gamma rays so that it could be detected through the plant walls; it should also be inseparable from phenol under the conditions of plant operation.

The most likely candidate was orthobromphenol, whose boiling point (194°C) is sufficiently close to that of phenol (182°C) to suggest that it might follow the phenol throughout the plant. This compound could be labelled with bromine-82, an isotope of 36 hours half-life, with beta- and copious gamma-ray emission. Irradiation of bromine with neutrons also produces bromine-80 (half-life 4½ hr) but this can be allowed to decay to a negligible amount and yet leave sufficient bromine-82 to be useful. Moreover, as bromine-80 emits gamma rays in only about 20% of its disintegrations, measurement of activity with a gamma detector is intrinsically weighted in favour of bromine-82.

Preliminary laboratory investigations, including solvent extraction and distillation, were therefore carried out to judge the suitability of o-bromphenol as a tracer for phenol. The method of preparation of the active compound was also relevant, since side-reactions might give impurities containing radioactive bromine which could give a false picture of the phenol distribution. From these experiments, described in the Appendix, it was concluded that o-bromphenol would be a satisfactory tracer for phenol in the plant, provided that the active o-bromphenol was sufficiently pure.

Planning the Full-scale Experiment

Having shown that o-bromphenol (Br^{82}) was a reasonably good tracer for phenol, the quantities necessary for adequate detection in the plant had next to be established. Fig. 1 shows diagrammatically the operation of the phenol extraction plant. The plant consists of three main parts: the treating unit, a multiplate tower where oil and phenol are counter-currently extracted; a solvent recovery section for the raffinate phase; and a solvent recovery section for the extract phase. (In fact, in the Fawley plant, two different feedstocks can be handled simultaneously. Two extraction towers and two systems for recovering phenol from the raffinate streams are provided, although the extract streams are combined. For simplicity this doubling of facilities is not shown in Fig. 1, but is nevertheless referred to in the following description of the work.)

Clearly, the most desirable detection system was one involving no alteration of the plant. Determination of the activity of the tracer in the actual plant pipelines—4 in. (10 cm) in diameter in most cases—would require the use of scintillation detectors, since these would in the circumstances provide the most sensitive method of measuring the gamma rays exitted by the Br^{82}. Refinery operating specifications limit the phenol content of the raffinate streams to a maximum of 0.005% and it was obviously desirable to be able to detect this or lesser concentrations. Calculations showed that about 20 curies of Br^{82} would be required to obtain this sensitivity. This amount of radioactivity was obviously too large to be handled conveniently or safely.

In theory, the most sensitive method of determination would be to place a counter at the centre of an infinite amount of liquid. While this could hardly be achieved in practice, the use of 200-gal. tanks was felt to be a reasonable approximation. The principal streams were therefore tapped into three 200-gal. tanks, one in each raffinate stream (T_1 and T_2) and one in the final extract stream (T_3). Two of these (T_1 and T_3) are shown in Fig. 1. Scintillation counters were placed in 5-in. (12.5-cm) diameter iron tubes fixed so that a counter head was approximately at the centre of each tank. Since the temperature of the oil streams was 70-80°C, to maintain counting reliability the counter heads were cooled to 20-30°C by rapid circulation of cold water through coils of plastic tubing. In this way the background radiation was kept quite low (approximately 18 counts per second), and a detectable count rate was obtained with as little as 0.005 micro-curies of Br^{82} per gallon. This concentration represents a total requirement of 450 millicuries for the plant experiment, and was considered to be a practical proposition.

To minimise any radiation hazard, personnel in the im-

TABLE I—Activity of Refinery Streams

	Activity, counts/min.
Phenol tank	2000
Phenol layer from phenolic water tank	3400
Aqueous layer from phenolic water tank	187
Raffinate stream	5
Extract stream	340

TABLE II—Treatment of Extract Stream

Treatment:	*Activity Left in Oil, %*	*Activity in Extracting Liquor, %*
Extracted with equal volume of:		
Nil	100	—
N $NaHCO^3$—cold	77	23
N Na^2CO^4—cold	81	19
N NaOH—cold	56	44
40% NaOH—1 hr, hot	6	94
Conc. HCl—1 hr, hot	7	93

TABLE III—Phenol Content of Extract Streams

Refinery	*Extraction Treatment*	*Phenol Content, %*
Fawley	30% of caustic soda solution (cold)	0.003, 0.004, 0.004
	30% of caustic soda solution (6 hr, hot)	0.009, 0.008, 0.010
Port Jérôme	30% of caustic soda solution (cold)	0.08
	5% of caustic soda solution (hot)	0.14
	30% of caustic soda solution (hot)	0.16

mediate vicinity were kept to a minimum until the tracer was in the plant stream, and all persons directly concerned with the experiment wore film badges and desimeters. Preliminary handling considerations were in line with safety measures laid down by the Atomic Energy Authority. Once the o-bromphenol was in the plant phenol stream, the dangers would be very much reduced and, in fact, would be much less than any danger from phenol itself. The relatively short half-life of Br^{82} (36 hr) was an advantage in this respect, since all measurable activity in the plant would be gone in a relatively short period and there was no danger of radioactivity reaching the consumer.

The Plant Experiment

Radioactive o-bromphenol was prepared and purified on a large scale by the method described in the Appendix. The material (activity approximately 370 millicuries) was taken to the refinery in a polyethylene bottle and opened there by cutting off the top with 10-ft pruning shears. To facilitate introduction of the tracer into the phenol system and to enable some control to be exercised over the rate of introduction, the o-bromphenol (62 ml) was poured into 14 gal. of oil contained in a drum in a sandbagged enclosure, the whole operation being carried out as quickly as possible to minimise the radiation dose. The phenol and oil were mixed with long-handled stirrers, and the oil injected into the phenol tank of the plant by a reciprocating pump over a period of 2 hr, this being the approximate cycle time of the phenol in the plant. The drum and pump were then flushed thoroughly with fresh oil to get all the activity into the plant.

The radioactivity of the raffinate and extract streams was measured by scintillation counters placed as described above at the centres of the 200-gal. tanks and connected to continuous chart recorders. The liquid levels in the tanks were kept as steady as possible during the recording period of 16 hr.

The detectors in the tanks showed the presence of activity about 1 hr after the injection of the o-bromphenol, and this reached a maximum in about 7 hr. The activity remained substantially constant thereafter, although the activity in the raffinate tanks was lower throughout than that in the extract tank (Fig. 2). No surges in activity were noted; the slight variations in count rate (about $\pm 6\%$) could be correlated completely with the slight rise and fall of the level of liquid in the tanks caused by difficulties in maintaining completely uniform flow rates. The flow rate through the raffinate tanks was approximately 3 gpm and that through the extract tank 6 gpm. Since the tanks each held about 175 gal. of oil, the contents of the raffinate tanks were turned over completely in about 1 hr and the extract tank in about $\frac{1}{2}$ hr. Thus, the absence of surges in the continuous radiation record shows that phenol concentrations throughout the plant did not vary significantly at any time during the experiment.

At intervals, samples from various parts of the plant were taken for subsequent laboratory measurement of activity. The results are given in Table I.

It will be seen that the extract was much more active than the raffinate and that the phenol from the phenolic water tank was more active than the main bulk of phenol. These facts suggest that some separation of the radioactive o-bromphenol from the phenol may have occurred. The phenolic water comes from the steam stripping towers at the end of the phenol recovery systems, and it is during its passage through these systems that the o-bromphenol could have become concentrated in the raffinate or extract streams. That this concentration apparently occurs to a very large extent in the extract stream but not in the raffinate is not altogether surprising, as each raffinate stream contains only a small proportion of phenol which can easily be removed in two small towers, whereas the extract stream contains the bulk of the phenol and this must be removed in one large tower and two smaller ones successively. Opportunities for fractionation of the o-bromphenol from the phenol would thus be correspondingly greater in the extract system.

The very high level of activity in the final extract stream —if directly related to phenol content—would imply absurdly high phenol losses from the plant. However, it was found that a large proportion of the o-bromphenol in the extract was in a combined form, for only 40-50% of the activity could be removed with cold normal caustic soda solution, the standard analytical procedure for extracting phenols. That this removable radioactivity was in fact due to o-bromphenol (Br^{82}) was proved by the addition of carrier o-bromphenol, extraction with alkali and fractional distillation of the material obtained by acidifying the alkaline solution. Some of the remaining activity in the extract stream could be removed by boiling for 1 hr with normal caustic soda solution or with concentrated hydrochloric acid. Even then, 6-7% of the activity could not be extracted. Data are given in Table II.

These results suggested that the o-bromphenol had formed a complex with the extract, the reaction taking place on the phenolic group. Thus, for instance, the o-bromphenol may have esterified with naphthenic acids in the oil, for such compounds would be hydrolysed by hot acid or alkali, as was observed.

Of course, if the o-bromphenol underwent chemical reaction with the extract stream, it is entirely probable that phenol itself should also do so, becoming combined in a form which escapes the routine chemical analysis. Confirmation of this theory was obtained from tests on extract stream samples taken later during normal plant operation at Fawley, as well as at the Port Jérôme refinery of Esso Standard S.A. Française. As the data in Table III show, extraction with hot caustic soda removed about twice as much material as the usual cold extraction.

The higher extraction with hot causic soda might have been due to the extraction of naphthenic acids (the phenols are normally not identified as such; the extract residue is merely weighed), but this was disproved in this case by acidification and identification of the extract as phenol by U.V. spectrometry.

There was also the possibility in the plant experiments that bromine had separated from the o-bromphenol and subsequently reacted with other compounds in the extract. The small amount of water which finds its way into the phenol stream is flashed off at one stage in the process by passage through a furnace at 300°C. Hydrolysis at this stage seemed the most likely point at which bromine would have become detached, but as examination of the water distillate showed no Br^{82} which could be precipitated as silver bromide, this possibility was rejected.

Conclusions

The use of radioactive o-bromphenol (Br^{82}) as a tracer for phenol losses in the phenol extraction plant at Fawley refinery was only partially successful in that some fractionation of the o-bromphenol from the phenol took place. This fractionation was shown particularly clearly by the large activity of the phenolic water sample taken at the end of the run.

Tests on the extract stream, which because of this fractionation effect were more radioactive than had been expected, showed that only half of the activity was due to o-bromphenol itself. Some two-thirds of the remainder was in the form of a non-phenolic complex, hydrolysable by hot alkali; the remaining activity appeared to be associated with a nonhydrolysable material. As o-bromphenol was recovered on hydrolysis of the complex, the bromine atom

was probably not entering into the reaction, complexing being due to a reaction of the phenolic group.

In view of the probability that phenol reacts in a similar way to o-bromphenol, part of the phenol losses in the plant may have been due to reaction with materials in the extract stream, for the phenol in the complex would not be deected by the routine cold caustic soda extraction. In a few tests, rather more than double the amount of phenol was recovered by hot caustic soda extraction, and this would therefore raise the accountable phenol losses from about 0.15 tons/day to around 0.3 tons/day. With the unhydrolysable residue, a total loss of very approximately 0.35 tons/day of residual phenol in the raffinate and extract streams can be recognised. When the miscellaneous mechanical losses of some 0.15 tons/day are added to this, it can be seen that just about all of the 0.5 tons/day of phenol losses originally reported are accounted for. There was good evidence that surges of phenol were not responsible for the losses.

TABLE AI—Irradiations

Irradiated Material	*Irradiation*		*Subsequent Decay*	*Retention of Br^{82}, %*
	Time (hr)	*Neutron Flux (PF)*		
1. Carbon Tetrabromide and phenol (9:1 w/w)	1	10	3·5	33
2. Carbon Tetrabromide and phenol (9:1 w/w)	1	14	9	39
3. Dibromobenzene and phenol (9:1 w/w)	1	14	9	62
4. o-bromobenzene and phenol (1:2 molar)	1	10	5	46
5. o-bromphenol	1	11	3	73.5
6. o-bromphenol	1	10	9	87
7. o-bromphenol	1	10	6	82.5
8. o-bromphenol	170	15	8	89
9. p-bromphenol	1	10	2.5	80

PF—a pile factor of 1 is equivalent to a thermal neutron flux of 10^{11} neutrons/cm² sec.

TABLE AII—Impurities Present in Irradiated Samples

Target Material	*Carbon Tetrabromide and Phenol (9:1 w/w)*	*o-bromphenol*		*o-bromphenol and phenol (1:2 molar)*	*p-bromphenol*
Active o-bromphenol, %	15	21	30	16	5
Impurities, %					
p-bromphenol	25	26	39	28	57
2:4 dibromphenol	—	9.3	—	—	—
2:4:6 tribromphenol	—	1.9	—	—	—
non-phenolic, B.P. 200-250°C.	—	22	—	0.6	2.3
brombenzene	—	—	2	0.4	3.3
p-dibrombenzene	—	—	0.1	—	0.6

TABLE AIII—Distribution of Br^{82} (Bromphenol) and Phenol Between Phases at 60°C

	Phenol Concn. in each phase, %	*Activity counts/min.*	*Activity/Phenol*
Crude radioactive o-bromphenol			
Raffinate	22.1	1370	62.0
Extract	70.0	4300	61.4
Purified radioactive o-bromphenol			
Raffinate	22.3	126	5.65
Extract	70.0	388	5.54

TABLE AIV—Distillation of o-bromphenol-phenol-oil Mixture (at 5·10 mm Hg pressure)

Experiment	*1*		*2*		*3*	
o-bromphenol, g	3.7		5		10	
phenol	96		95		190	
oil, g	42		42		94	
	Fraction	*Activity*	*Fraction*	*Activity*	*Fraction*	*Activity*
	20	8870	24.7	3550	35.0	2210
	20	8560	23.6	3120	32.8	2070
	20	7550	14.3	2840	31.8	1800
	20	5900	15.3	2790	31.6	1540
	20	13800	8.5	2860	29.7	1440
	15	900	Residual* oil	750	15.0	1430
	(oil) Residual oil	30			17.0 Residual oil	1570 3

* (Residual oil contained 480 counts/min. non-phenolic material.)

ACKNOWLEDGMENTS

The authors acknowledge with thanks the advice and assistance with counting equipment given by Mrs. N. Ball (née Wildblood).

APPENDIX

(1) *Materials and Apparatus*

Ortho-bromphenol used for irradiations was "pure" grade material from B.D.H. purified further by fractional distillation. Other chemicals were of "pure" grade.

Radioactivity determinations during the preliminary experiments were carried out using an M.6H liquid Geiger-Müller counter (20th Century Electronics) with conventional scaling equipment. Samples from the plant were examined using an Ecko well-type scintillation counter, standardised for absolute activity with a Br^{82} solution of known radioactivity; the efficiency of the counter was found to be 16%.

(2) *Preparation of Radioactive o-Bromphenol*

Three general methods of preparing o-bromphenol were considered:

(i) by exchange between the bromine of o-bromphenol and radioactive bromide ion under suitable conditions;

(ii) by synthesis using radioactive bromine; and

(iii) by neutron bombardment of o-bromphenol or of mixtures likely to form it.

Preliminary work soon showed that Method 1 was not promising since reactions were slow, which was undesirable because of the short half-life of Br^{82}. Method 2 gave unsatisfactory yields and required a large number of handling stages with highly active material. Method 3 was in fact eventually used for the large-scale preparation owing to the relative simplicity of operation and the large amount of activity required.

Production of labelled o-bromphenol is possible by the irradiation of o-bromphenol itself or of mixtures of bromine-containing compounds (e.g. carbon tetrabromide) with phenol. In both cases radioactive impurities due to the production of bromine, bromide ion and other radioactive organic bromine compounds were expected. Table A1 gives results of a preliminary investigation using o-bromphenol, p-bromphenol, and mixtures of carbon tetrabromide or di-brombenzene with phenol. The table also shows the retention of Br^{82}. This retention factor is the fraction of the total radioactive bromine which is found in the organic form (irrespective of compound) and is determined by separation of inorganic bromine by aqueous extraction with sulphurous acid from a solution of the target material in ether. To allow Br^{80} (4-hr half-life) to decay, and for practical reasons, there was always a delay between irradiation of the samples and the determination of retention factor; this is shown in the table as a decay time.

The retention varied with the system and the duration of irradiation. The highest results were obtained for o-bromphenol.

In order to obtain some idea of the other compounds produced during irradiation of the target mixtures, the irradiated material was dissolved in ether, the inorganic bromine extracted with sulphurous acid and the retention factor determined. Appropriate carriers were then added to the solution, and after boiling off the ether, the mixture was carefully fractionated under reduced pressure using a 30-cm Widmer column. Appropriate fractions were collected and the middle cuts used for the determination of the bromine-82 activity. From the weight of the aliquot, the weight of the carrier added and the radioactive content, the fractional distribution of the bromine-82 in the various compounds could be expressed as percentages of the total retention.

To confirm the results from the distillation, solid derivatives of the various compounds were also prepared and crystallised to constant specific activity; three crystallisations were usually sufficient to obtain this condition. Results obtained agreed well with those from the distillation method. The following derivatives were prepared:

(i) From o- and p-bromphenol, 2:4-dibromphenol and tribromphenol were prepared the bromphenyloxyacetic acids (purified by aqueous recrystallisation).

(ii) From o- and p-bromphenol, by treatment with benzoyl chloride in pyridine, were prepared the bromphenyl benzoates.

The yield of tribromphenol was also obtained directly by aqueous recrystallisation to constant melting point and specific activity.

Neutral materials (brombenzene, dibrombenzenes and other similar compounds) were estimated without separation of the components by extraction of the target material in ether with dilute caustic soda solution. After washing with water, the radioactive content of the ether solution was determined as described. Brombenzene and o- and p-dibrombenzenes were separated by distillation; as a check, brombenzene was also converted to p-nitrobrombenzene by treatment with nitric-sulphuric acid mixture, and the derivative recrystallised.

In this way the analyses given in Table AII were found; results are expresed as a percentage of the total retained Br^{82} activity.

(3) *Distribution of o-bromphenol in Phenol-oil Mixtures*

To examine the behaviour of mixtures of o-bromphenol and phenol in the extraction of oil, an unrefined feedstock (160 ml) and phenol (160 ml) containing irradiated o-bromphenol were kept at 60°C and shaken occasionally for 3 hr. The phases were then separated and the distribution of radioactivity between them measured directly in the "liquid" Geiger counter. The phenol was determined by dissolving the phenol-oil solutions in ether and extracting them with 2N. caustic soda. These solutions were then acidified, the phenol brominated with a known excess of KBr and KBr0, and the excess bromine determined in the usual way with iodine and thiosulphate. The results given in Table AIII show that the radioactivity was distributed between the phases in the same ratio as the phenol. Furthermore, it seemed that purification of the irradiated o-bromphenol had little effect on the total distribution of the organic bound Br^{82}.

(4) *Distillation of Phenol and o-bromphenol Mixtures*

The recovery of phenol by distillation forms a significant part of the plant operation. To examine the behaviour of o-bromphenol on simulated plant distillation in the presence of phenol and oil, a solution of the labelled bromphenol in phenol, added to the unrefined lubricating oil in the correct proportions, was fractionated at about 5 to 6 theoretical plates using a 5-cm Widmer column with a reflux ratio of 1:1 and a distillation rate of 4 ml/min. from the 200-ml bulk. The active content of each fraction was measured by a Geiger counter with the results given in Table AIV.

In the three experiments listed, the radioactive o-bromphenol was prepared in three ways giving three purity levels. In Experiment 1 (Table AIV), it can be seen that the last phenol fraction contains much more active bromine

Continued on page 722

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FLOW COEFFICIENT OF PIPE CONSTRICTIONS—PART II

Flow coefficient and operational correction factors: comparison of theory with experimental results

by T. H. REDDING, M.Sc., F.Inst.P., A.M.I.Mech.E.*

ALTHOUGH throttling devices are so much a feature of hydraulic engineering practice, they have not, in general, been sufficiently investigated experimenally to provide data for analytical purposes.

An exception however is the case of throttling devices used for metering purposes, and particularly the low and high ratio A.S.M.E. type metering nozzles and metering orifices of the A.G.A.—A.S.M.E.† form—the essential features of which are shown in Figs. 4.1, 4.2 and 4.3 respectively. (These devices are, in fact, forms of long-radius elliptical metering-nozzles and sharp-edged orifices, the first detailed specification of which appeared in 1937[12] and 1935[13] respectively: subsequently, the devices were accepted by the A.S.M.E.[5] and the A.G.A.[6, 7, 8] as standard metering devices.) Even in these simple cases however, information is not as complete as one would desire since the α versus R characteristics are available for a few, characteristic, rather than representative, positions of the pressure tappings—taken at distances l_1/D upstream and l_2/D downstream of the entrance section of the throttling device.

A.S.M.E. and A.G.A. Throttling Devices: A.S.M.E. Nozzles

Flow Characteristics

Experiments on A.S.M.E. nozzles have been designed to provide detailed flow coefficient data in various sized mains with corner tapped installations and with installations where so called pipe-wall taps‡—taken $1D$ upstream and $0.5D$ downstream of the entrance section of the nozzle —are used. It is unfortunate, from an analytical point of view, that comprehensive data are not available for other tapping positions needed to complete our knowledge of the D, R, l_1/D, and l_2/D dependence of the flow-coefficient α.

Basing our representation of the "α, D, R, l_1/D, l_2/D" relationship on sets of curves which, for a given value of m, show α versus R for selected values of D, necessitates a "mosaic" of sets of such curves, each vertical column of which relates to a given selected value of l_1 and each horizontal row to a selected value of l_2. The location of "corner tapped" and "pipe-wall tapped" nozzle characteristics within such a system, with l_1/D and l_2/D set at values 0, 1, $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, etc., is shown in Fig. 5 (which also shows similar data for A.G.A.-A.S.M.E. orifices which will be considered later); whilst, for reference purposes the α versus R characteristic relating to nozzles with corner and pipe-wall taps are shown in Figs. 6.1 and 6.2 respectively. These curves have been computed from calibration data given by Beitler and Bean[14] and by Bean, Beitler and Sprenkle,[15] which in its original form, determines, for selected values of m and D, the characteristics C versus R for corner taps, and C versus R_d in the case of pipe taps—where $C = \alpha(1 - m^2)^{\frac{1}{2}}$ and $R_d = R/m^{\frac{1}{2}}$.

These characteristics follow the general trend of converging flow, in that they become more dependent on R as R decreases, α decreasing with decreasing values of R: this is mainly the result of E (approximately constant at high Reynolds numbers) increasing as R falls below approximately 10^6 as may be seen from equation (26). That this effect is less marked at lower values of m arises from the higher accelerative forces rendering the flow pattern less dependent on the viscosity, and thus of the Reynolds number of the flow. (The fact that C_1m^2 increases with decreasing R with a consequent tendency to increas α is of secondary importance over the range of Reynolds number under consideration.) Also as R decreases the probable error increases, so much so, that it would be imprudent to use the above characteristics, except in the region where α is sensibly independent of R, for analytical purposes.

However, at high Reynolds numbers reference to the constitutional formula for the flow coefficient (equation (26)) will provide an explanation for the facts that (a) the coefficients relating to corner taps are less than those relating to pipe taps and (b) the coefficients for small diameter mains are greater or less than those for large diameter mains according to whether corner or pipe taps are used.* Thus, the fact that, at high Reynolds numbers, the coefficients for corner taps are less than those relating to

* T. H. Redding is at British Scientific Instrument Research Association, Chislehurst, Kent.

† A.G.A.—American Gas Association. A.S.M.E.—American Society of Mechanical Engineers.

‡ Although in common use in connection with metering nozzles, this is not a good term to describe this position of the pressure tappings, since it is liable to be confused with the term "pipe-taps" as used in conjunction with *metering orifices* to indicate a pair of pressure tappings taken 2.5D upstream and 8D downstream of the entrance section of the orifice.

* In applying equation (26) to nozzle flow $l_1 = 1/m$ and $l_1 = 1$ for corner or pipe-wall taps since, in both cases, the upstream tapping is in the wall of the unrestricted pipe and the downstream tapping in a position which registers, substantially the pressure in the nozzle-throat—see Figs. 4.1(b) and 4.2(b).

pipe taps, by an amount which decreases with decreasing m, is due to the severe curvature of the stream lines immediately upstream of the nozzle—see Fig. 7: this causes θ_1 (which is always greater than unity) and, to a much lesser degree Y_1, to increase as the upstream tapping approaches the corner position. Reference to equation (26) shows that such changes in θ and Y_1 will cause α to decrease as the upstream tap approaches the corner position, providing that the energy loss ($\triangle E$ say) over the 1 D length of main separating the upstream "pipe-wall" and "corner" taps is insignificant. [This curvature of the streamlines in the immediate upstream vicinity of throttling devices also gives rise to the so-called "plate-impact pressure", i.e., an increase in the value of the static pressure in the immediate upstream vicinity of throttling devices (see Fig. 7): theoretically this is at once apparent if Bernouillis' theorem is applied (with downstream values of $\theta_1\ \mu_1 > 1$) to that portion of the stream between an upstream pipe section sufficiently far from the constriction to ensure sensibly parallel stream lines and a pipe section immediately upstream of the entrance-section of the constriction itself] Even though θ_1 tends to increase with decreasing m, the excess of the coefficient relating to pipe-wall taps over that of corner taps decreases with decreasing values of m.*

Again, for corner tapped nozzles, at high Reynolds numbers the increase in the value of α for decreasing values of D can be explained in terms of C_1 and μ_1 (see Fig. 7).† Of these quantities C_1 has already been discussed, whilst Betz[16] has shown that $\mu_1 < 1$, i.e., that an appreciable, though small, contraction of the fluid stream takes place in the immediate upstream vicinity of a sudden pipe-constriction: furthermore, according to Betz such contraction is associated with a point of separation which tends to approach the "corner" between the pipe and the constriction as the approaching velocity profile tends to uniformity across the pipe section.

Thus, as D decreases, the upstream (unconstricted) velocity profile will tend to acquire increased curvature (due to increase in the relative roughness) with resulting increase in C_1 and decrease in μ_1 due to recession of the upstream point of separation away from the corner of the nozzle. Equation (26) shows that both these effects tend to increase the value of α. (Conceivably, Y_1, θ_1 and E are also sensitive to changes in D but not to the same extent as changes in C_1 and μ_1—in any case, indications are that θ_1 and E would tend to increase with decreasing values of D, with consequent *decrease* rather than an increase in the value of α.) Alternative explanations of this effect, based solely on the factor C_1 increasing with decreasing values of D (which is the usual explanation of the fact that α increases with increasing relative roughness) is probably an oversimplification in so far as corner tapped nozzles are concerned; since computed increases in the value of C_1 required to effect the observed changes in α appear to be considerably higher than theory can admit, even when no allowance is made for the effect of probable increases in θ_1 due to decreasing values of D.

The reverse effect, which occurs when pipe-wall taps are used—when, at high Reynolds numbers, α decreases with decreasing values of D—is difficult to explain. However, some results by Bean and Beitler[17] indicate that the effect of streamline curvature extends some distance upstream of the nozzle: thus, it is possible that, even at the upstream pipe-wall tapping, $\theta_1 \neq 1$. In these circumstances a decrease in the value of α with decreasing D could be explained, in the absence of any stream-contraction, by increasing values of θ_1 more than compensating for the aforementioned increase in value of C_1.

A.G.A.—A.S.M.E. Orifices

In so far as A.S.M.E. orifices are concerned, experimental work has resulted in the determination of the α versus R characteristic relating to various pipe sizes for corner tapped orifices and for so-called flange, vena-contracta, radius and pipe tapped installations: we have not, as yet, access to accurate systematic knowledge of the α versus R characteristics for other tapping positions.

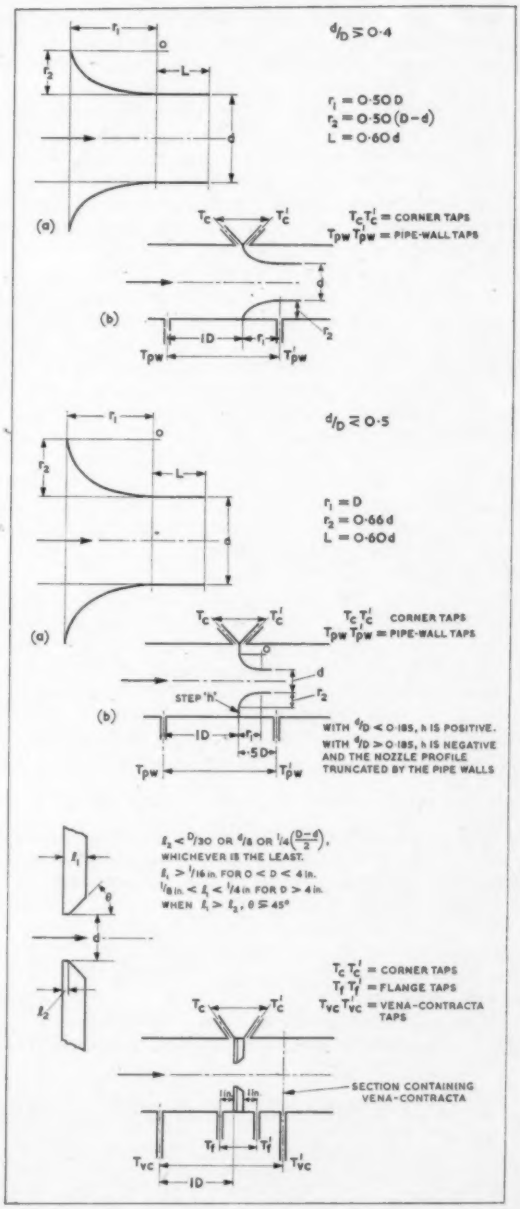


Fig. 4.1

Fig. 4.2

Fig. 4.3

Fig. 4.1. *A.S.M.E. high-ratio metering nozzle.*
Fig. 4.2. *A.S.M.E. low-ratio metering nozzle.*
Fig. 4.3. *A.G.A.—A.S.M.E. metering orifice.*

* Thus assume (a) that the pressure drop across the pipe-wall taps is substantially the same as between the upstream pipe-wall tap and a tap within the nozzle-throat, for which tappings $C_1 \simeq \mu_1 \simeq \theta_1 \simeq 1$, $Y_1 \simeq 0$, $C_2 \simeq \mu_2 \simeq \theta_2 \simeq 1$, $Y_2 \simeq O$, $E = E_{pw}$ (say) and (b) that the pressure drop across the corner taps is substantially the same as between the upstream corner tap and a tap within the nozzle-throat, for which tappings $C_1 = C'_1$, $\mu_1 = \mu'_1$, $\theta_1 = \theta'_1$, (say); $Y_1 \simeq \theta$, $C_2 \simeq \mu_2 \simeq \theta_2 \simeq 1$, $Y_2 \simeq 0$, $E = E_c$, (say), with $E_c \simeq E_{pw} \simeq 0$, and apply Equation (26) to give $\alpha^2_{\text{pipe-wall}}/\alpha^2_{\text{corner}} = 1 + m^2(1 - C'_1/\mu'_1{}^2\theta_1{}^2)/(1 - m^2)$. If we assume, as is reasonable, that the overall value of $m^2(1 - C'_1/\mu'_1{}^2\theta'_1{}^2)/(1 - m^2)$ decreases with decreasing m (in spite of θ_1 itself tending to increase as m decreases) the above expression shows decreasing values of $\alpha_{\text{pipewall}}/\alpha_{\text{corner}}$ with decreasing values of m.

† This figure is for illustration only and is not to scale: furthermore the scales of 100 $((P_1 - P_1')/(P_1 - P_2))$ and 100 $((P_2 - P_2')/(P_1 - P_2))$ are necessarily approximate.

However the discussion which follows is confined to installations with corner taps, flange taps (with upstream and downstream taps 1 in. upstream and 1 in. downstream of the entrance section of the orifice respectively) and vena-contracta taps* (with the upstream tap $1D$ upstream of the entrance section of the orifice and the downstream tapping at that pipe-section which contains the vena-contracta).† The system previously used for representing nozzle coefficient-data can be used to set into perspective the α versus R characteristics of corner, vena-contracta and flange-tapped orifices—as shown in Fig. 5. For reference purposes these characteristics are shown in Figs. 8.1, 8.2 and 8.3 which, with the exception of the curves relating to corner taps, have been computed directly from calibration data given by Beitler.[13] The data relating to corner taps however, has been evaluated from a National Bureau of Standards evaluation of Beitlers' results which has been reported, in summary form, in reference 18. (This analysis refers to ranges of D and m defined by 10 in. $> D >$ 2 in. and $0.49 > m > 0.0225$ respectively, but in constructing the curves of Fig. 8.3, the relevant empirical formulæ have been applied to values of m up to 0.5625 and to Reynolds numbers approximately one decade above and below the range of Reynolds numbers used in the original experiments.)

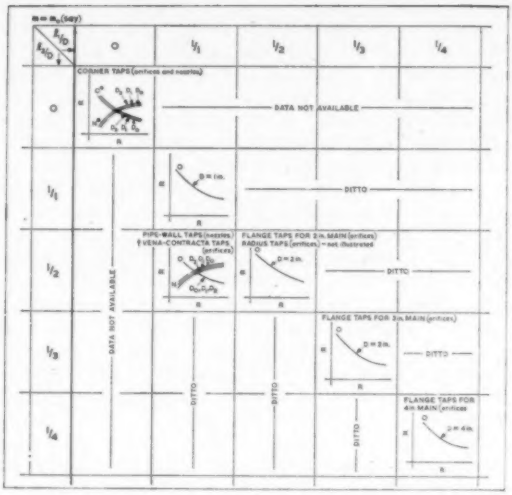
Unlike the characteristics of metering nozzles, all the above curves show that α increases with decreasing R, this being a condition which arises from decrease in Reynolds number having the effect of simultaneously increasing both E and μ_2. At first, these effects, operating through Equation (26), almost balance, so that no change in the flow coefficient is observed, but later the increase in μ_2 tends to become the most effective factor with consequent increase in the value of α. If R is still further reduced, μ_2 tends to a constant value and increasing values of E—in spite of $C_1 m^3$ increasing slightly with decreasing R—gives rise to decreasing values of α. The resulting "peak" and subsequent positive slope of the α versus R characteristic is however, outside the range of values of R shown in Figs. 8.1, 8.2 and 8.3.

As with nozzles, the dependence of the flow coefficient on Reynolds number tends to become less severe as the area ratio decreases.

Again, as with nozzles, the probable error of the experimental results increases rapidly as the Reynolds number decreases, but at high Reynolds numbers we may refer to Equation (26) to explain certain characteristic and comparative features of the α versus R relationships appropriate to the aforementioned positions for the pressure taps. For this purpose, we notice that, for pipe orifices, both the upstream and downstream pressure taps are in all cases taken in the wall of the pipe itself, so that $j_1 = j_2 = \frac{1}{m}$; also we shall again assume that, at a given Reynolds number, E is sensibly independent of the position of the pressure taps seeing that the pressure taps under consideration are in the near vicinity of the orifice itself.

Thus, at high Reynolds numbers, variation in and separation upstream of a *corner tapped* orifice could contribute towards the marked dependence of the flow coefficient on the pipe diameter. As compared with nozzles, this effect would be enhanced by virtue of any shift (upstream) of the point of separation (previously attributed to smaller diameter pipes) having the effect of slightly reducing the curvature of the bounding upstream streamline and thus increasing the coefficient of contraction μ_2, in the immediate downstream vicinity of the orifice. Again, this effect could be expected to become less apparent as the area ratio decreases.

The main feature of *vena-contracta* tapped orifices is their virtual independence, at high Reynolds numbers, of the pipe diameter. It would appear that increase in α due to decreasing values of D causing an increase in C_1 are almost completely compensated by the accompanying increase in the factor θ_1. [When this is not the case, and particularly when the flow coefficient tends to decrease with decreasing pipe diameter, Beitler[13] suggests that the possibility of experimental errors must not be overlooked—this is, in fact, the case at high and low values of m: consequently, the following observations refer to values of m within the range $0.5625 > m > 0.16$.] Again, due to streamline curvature immediately upstream of the orifice, the coefficients for vena-contracta taps are, in general, greater than those of corner taps, with a diminishing difference between these coefficients at the smaller values of m. The fact that, at very low values of m (i.e. $m < 0.20$), the coefficients relating to vena-contracta taps are slightly less than those for corner taps, can be explained in terms of the amount of jet contraction which occurs downstream of the orifice: thus, as we recede downstream from the orifice the increasing con-



* O and N indicate that curves refer to A.S.M.E. orifices and nozzles respectively. The diagrams are for illustration only and are not to scale: in particular, α for nozzles and α for orifices are not plotted to a common scale.

† For the purpose of this illustration it is assumed that the vena-contracta occurs at a distance $0.5D$ downstream of the orifice: this, however, is an approximation since, in practice, the vena-contracta depends to some degree on the value of m.

The above sequence of values for l_1/D and l_2/D have been chosen for the above illustration, since, with the exception of data relating to orifices with pipe (or full-flow) taps, it conveniently includes all the available data on metering nozzles and orifices (data for pipe-tapped orifices would have to appear in rectangles corresponding to $l_1/D = 2.5$ and $l_2/D = 8.0$). The diagram can clearly be extended in both directions to include values of l_1/D and $l_2/D < 1/4$.

Purely from the point of view of accumulating data for analytical studies, it is highly desirable that, eventually, sufficient data shall be accumulated to permit interpolation on all scales; so that, in effect, we would then be able to derive the α versus R characteristic for any combination of m, D, l_1/D and l_2/D.

Fig. 5. Schematic showing availability of flow coefficient data relating to A.S.M.E. metering nozzles and A.G.A.-A.S.M.E. orifice-plates.

* Other taps for which flow coefficient data is available (viz. radius and pipe taps) are not considered in this discussion since (a) only very slight differences are apparent between the flow coefficients relating to radius taps (located at distances 0.5D upstream and downstream of the entrance section of the orifice) and the aforementioned vena-contracta taps, and (b) the flow coefficient for pipe taps (located at distances 2.5D upstream and 8D downstream of the entrance section of the orifice) is so much larger than for corner taps that the value of the relevant operational correction factor (when corner taps are considered as standard) falls far outside the range (.95 to 1.05) previously set for these factors in so far as this discussion is concerned.

† For the range of Reynolds numbers considered in this paper, the position of the vena-contracta is sensibly stationary. At low Reynolds numbers however, the vena-contracta tends to become nearer the orifice.

traction of the jet reduces the flow coefficient (by virtue of decreasing μ_2 in equation (26)) which, at low values of m could more than compensate for the increase in α which occurs (due to reduced streamline curvature) when the upstream tap recedes to a position $1D$, upstream of the orifice-entrance.

For *flange-tapped* orifices, with area ratios within the range $0.5625 \geqslant m \geqslant 0.16$, noting that their coefficients at high Reynolds numbers are greater than those relating to corner taps, the difference between the coefficients decreases with decreasing m and, to a lesser degree, with increasing values of D—since as the flange taps are at fixed (absolute) distances (i.e. 1 in.) upstream and downstream of the orifice, both l_1/D and l_2/D decrease with increasing values of D to give almost corner tapped conditions when D is greater than 10 in. say (when $l_1/D = l_2/D = 1/10$). However, as with vena-contracta taps, the coefficients relating to flange taps at low values of m are slightly less than those for corner tapped installations. Furthermore, as D decreases towards $D = 2$ in., l_1/D and l_2/D approach the value 0.5 and the coefficients for flange and vena-contracta taps are approximately the same; however, this effect is offset somewhat at high values of m due to the fact that the downstream flange tap takes up a position a little beyond the vena-contracta. Again, as with corner taps the flow coefficient is appreciably dependent on pipe diameter: however, since a decreasing pipe diameter implies increasing values of l_1/D and l_2/D and thus the positioning of the pressure taps in regions of more-nearly parallel stream lines, the flange tap coefficients at small values of D is less dependent on D than when corner taps are used.

The foregoing emphasises the importance of, and need for, extremely accurate determinations of the flow coefficient over large ranges of Reynolds numbers and at many positions of the pressure tappings for each of a number of carefully selected geometrical variations from the standard orifice and nozzle forms; such investigations are a necessary preliminary to a complete understanding of the constitution of the flow coefficient of metering devices. Again, the validity of any mapping of the flow field, by either theoretical or analogue techniques, could be judged to some degree by the extent to which it correlates with such experimentally determined relationships between the wall-pressure drop and the Reynolds number. Available data is by no means sufficient for comprehensive studies of this kind, since it only refers to a few positions of the pressure taps and has only been determined to a high order of accuracy ($\pm 0.2\%$ approximately) at high values of Reynolds number. Thus, for example, it would be unwise to use existing data on metering devices to explain the finer variations in the flow coefficient at low Reynolds numbers, e.g., the variation of α with D and with the position of the pressure taps: in fact, for analytical purposes, the probable error in determining the flow coefficient should not be greater than $\pm 0.1\%$.

Also, from an engineering point of view, high-accuracy determination of the flow coefficient would be of interest in modern metering practice where flow-rate determination to an accuracy of $\pm 0.1\%$ is often required. Moreover, a full understanding of the constitution of the flow coefficient would serve as a guide as to what precautions should be taken, in any given case, in order to realise the highest metering accuracy.

A.S.M.E. and A.G.A. Metering Throttles

Conditions for multiplicative compounding of operational correction factors

For any throttling device, proof as to whether or not experimental data substantiates the "combination" law represented by equation (6) can be decided:

(i) *directly:* by determining each of the functions k_a versus a, k_b versus b, k_c versus c by systematic experiment and

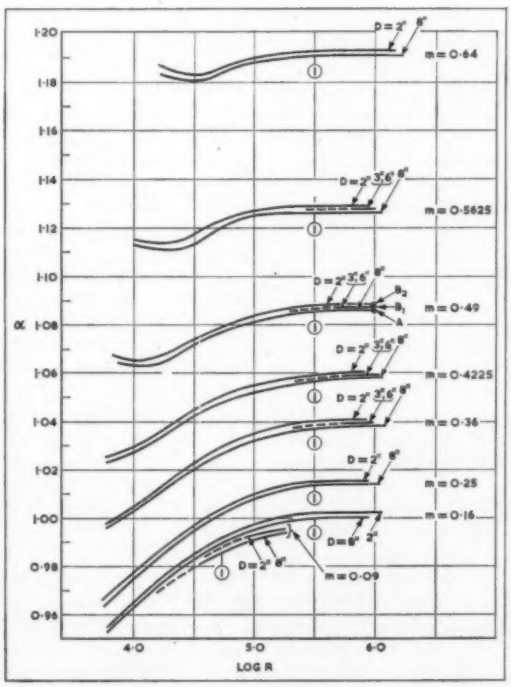


Fig. 6.1. A.S.M.E. nozzle with corner taps: α as a function of R *and* m*—after Beitler and Bean (see ref. 14).*

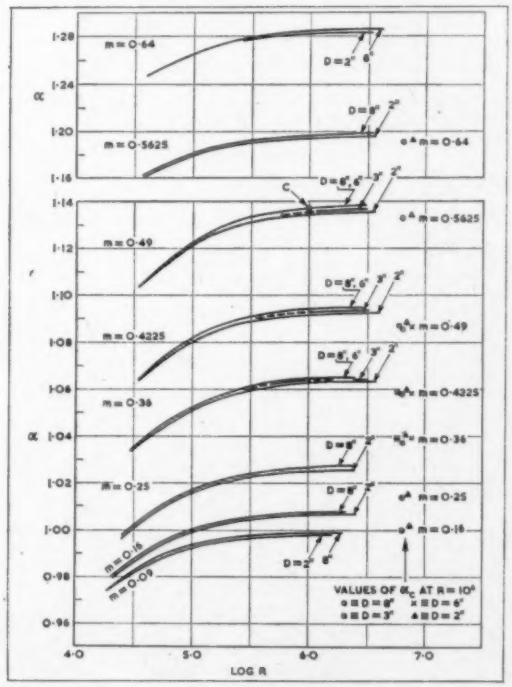


Fig. 6.2. A.S.M.E. nozzle with pipe-wall taps: α as a function of R *and* m*—after Bean, Beitler and Sprenkle (see ref. 15).*

thence comparing all experimentally available values of α/α_o with corresponding values of the computed product $k_a k_b k_c$ or,

(ii) *indirectly:* by application of the proposition that $\alpha = k_a k_b k_c \ldots k_m \ldots k_n)\alpha_o$ providing *any* group of ratios having the forms $\alpha_{abcd\ldots n}/\alpha_{bcd\ldots n}$, $\alpha_{bcd\ldots n}/\alpha_{cd\ldots n}$, $\alpha_{cd\ldots n}/\alpha_{d\ldots n}$ are—with the exception of *a* in the first ratio, of *b* in the second ratio and of *c* in the third ratio—independent of the values of all the other terms *a*, *b*, *c* ... *n*. Thus $\alpha_{abcd\ldots n}/\alpha_{bcd\ldots n} = f(a)$ $\alpha_{bcd\ldots n}/\alpha_{cd\ldots n} = f(b)$, $\alpha_{cd\ldots n}/\alpha_{d\ldots n} = f(c)$ where, in this formulation, and subsequently, we have indicated the flow coefficient of a system in which (say) *a*, *b*, *c*, *d*, differ from their values in the standard system by the symbol α_{abcd}. For example, if $\alpha_{abc} = \alpha_{RD\delta_1} = \varphi(R, D, \delta_1)$ where *R*, *D*, and δ_1 (the Reynolds number, pipe diameter and diametrical-distance l_1/D which separates the throttle and the upstream tap) all differ in value from their value in the standard system (for which $\alpha = \alpha_o$ when $R = R_o$, $D = D_o$ and $\delta_1 = (\delta_1)_o$) we can write $\alpha_{RD\delta_1} = k_R k_D k_{\delta_1} \alpha_o$ (with $k_R = \alpha_R/\alpha_o$, $k_D = \alpha_D/\alpha_o$ and $k_{\delta_1} = \alpha_{\delta_1}/\alpha_o$) if and providing $\alpha_{RD\delta_1}/\alpha_{D\delta_1}$ *is* independent of *D* and δ_1 *with either* $\alpha_{D\delta_1}/\alpha_{\delta_1}$ independent of δ_1 or $\alpha_{D\delta_1}/\alpha_D$ independent of *D**. The truth of the proposition is most easily proven by inductive reasoning considering, in turn, cases where α is known to be a function of one, two, three, etc., of the variables *a*, *b*, *c* ....

A.S.M.E. Nozzles

For the purpose of this discussion we consider the standard nozzle installation as being that relating to *corner* tapped nozzles with values of *R* and *D* such that the value of α is, sensibly, independent of these parameters. Evidence as to what extent multiplicative compounding of the operational correction factors is permissible when the pressure taps are moved to occupy either one (or both) of the positions appropriate to pipe-wall taps, and when the Reynolds number and pipe diameter change from their values in the standard system, is given at once by "reconstituting" the curves of Figs. 6.1 and 6.2 according to the formulæ

$$\alpha_{RD} = k_R k_D \alpha_o \text{ for corner taps} \quad \ldots . (51)$$

$$\alpha_{RD\delta_1\delta_2} = k_R k_D k_{\delta_1} k_{\delta_2} \alpha_o \text{ for pipe-wall taps} \quad \ldots . (52)$$

where

α_o = flow coefficient relating to the standard system—i.e., with *R* and *D* at such values (R_o and D_o) as to ensure that α is sensibly independent of these variables. [For the purpose of this analysis we may take log $R_o = 6.0$ and $D = 8$ in—so that if, for example, $m = 0.49$, α_o would be taken from the point A on Fig. 6.1.]

* Alternatively, the proposition holds good if $\alpha_{RD\delta_1}/\alpha_{\delta_1 R}$ is independent of δ_1 and *R* with either $\alpha_{\delta_1 R}/\alpha_{\delta_1}$ independent of δ_1 or $\alpha_{\delta_1 R}/\alpha_R$ independent of *R*; *or again*, providing $\alpha_{RD\delta_1}/\alpha_{RD}$ is independent of *R* and *D* with either α_{RD}/α_R independent of *R* or α_{RD}/α_D independent of *D*.

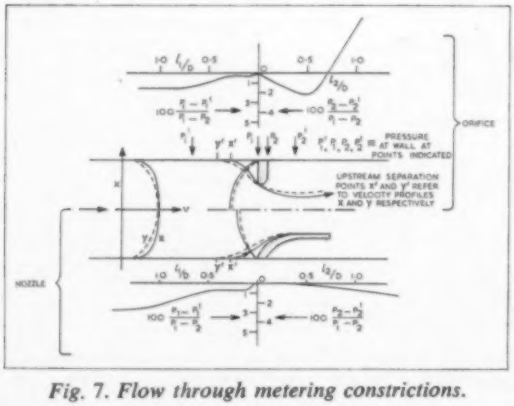

ORIFICE
NOZZLE
PRESSURE AT WALL AT POINTS INDICATED
UPSTREAM SEPARATION POINTS X' AND Y' REFER TO VELOCITY PROFILES X AND Y RESPECTIVELY

Fig. 7. Flow through metering constrictions.

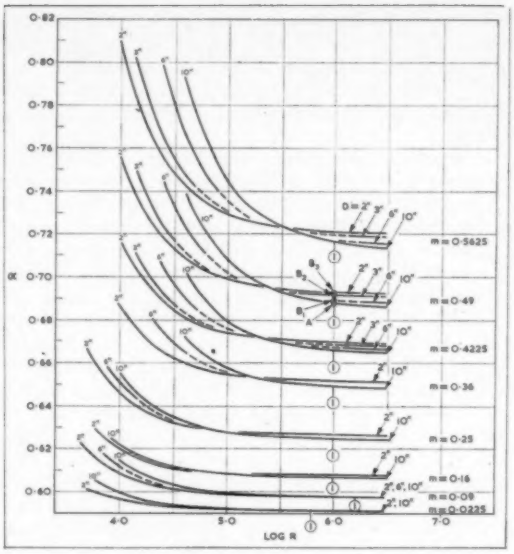


Fig. 8.1. A.G.A.—A.S.M.E. orifice with corner taps: α as a function of R *and* m*—after Bureau of Standards analysis of Beitler's results (see refs. 18 and 13).*

α_{RD} and $\alpha_{RD\delta_1\delta_2}$ are the values of corner and pipe-wall tapped coefficients in a pipe of diameter D at Reynolds number *R* (this being in accordance with the general nomenclature mentioned previously, wherein α_{abcd}, for example, refers to the coefficient of a system in which only the variables *a*, *b*, *c* and *d* differ from the values they assume in the "standard" case). Again, for convenience, the symbols δ_1 and δ_2 have been used to indicate l_1/D and l_2/D, the diametrical distances, from the entrance section of the nozzle, of the upstream and downstream pressure taps in the case of the pipe-wall tapped installation.

k_R, k_D, k_{δ_1}, k_{δ_2} are the operational correction factors relevant to the variables *R*, *D*, δ_1, δ_2 respectively, and which are derived from particular points of the corner and pipe-wall tapped flow characteristics as follows:

Values of k_R as a function of R. These are computed from curves ① of Fig. 6.1 using the (definition) equation $k_R = \alpha_R/\alpha_o$, where α_R is the flow coefficient of a corner-tapped nozzle in a main of diameter D_o at Reynolds number *R*. The resulting characteristics k_R versus *R* for various values of *m* is shown by curves (a) of Fig. 9.

Values of k_D as a function of D. These are computed from the corner-tapped coefficients relating to $R = R_o$ using the definition-equation $k_D = \alpha_D/\alpha_o$ where α_D is the flow coefficient at Reynolds number R_o in a corner tapped installation in a main of diameter *D*. (Thus, if $m = 0.49$, α_D would be taken from points such as B_1, B_2 on Fig. 6.1). The resulting characteristic k_D versus *D* for various values of *m* is shown by curves (b) of Fig. 9.

Values of ($k_{\delta_1} \times k_{\delta_2}$). The terms k_{δ_1} and k_{δ_2} cannot be calculated separately from the data presented in Figs. 6.1 and 6.2, since these curves give no information on the variation of the flow coefficient with changes in position of *one* only of the pressure tappings. However, as shown in Appendix I, the hydraulics of the system are such that, with reasonable accuracy, we may write

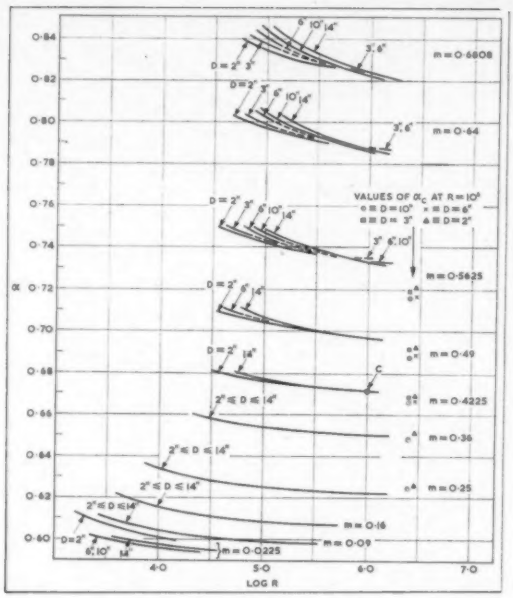


Fig. 8.2. A.G.A.—A.S.M.E. orifice with vena-contracta taps: α as a function of R *and* m*—after Beitler (see ref. 13).*

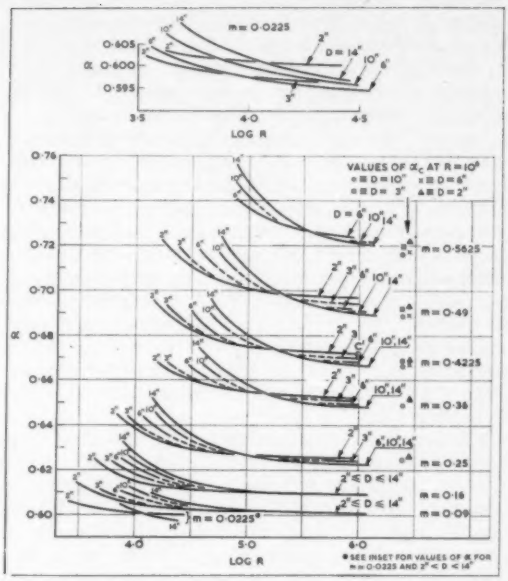


Fig. 8.3. A.G.A.—A.S.M.E. orifice with flange taps: α as a function of R *and* m*—after Beitler (see ref. 13).*

$$\alpha_{\delta_1\delta_2} = k_{\delta_1} k_{\delta_2} \alpha_O \qquad \ldots . (53)$$

where $\alpha_{\delta_1\delta_2}$ is the flow coefficient relating to pipe-wall (upstream *and* downstream) pressure taps when $R = R_o$ and $D = D_o$ (e.g., if $m = 0.49$, $\alpha_{\delta_1\delta_2}$ would be taken from the point C on Fig. 6.2). Values of the product $(k_{\delta_1} k_{\delta_2})$ and its dependence on the area-ratio m is shown by curves (c) of Fig. 9.

In so far as the "reconstitution" of the *corner-tapped* characteristics are concerned, such calculations show that coefficients calculated on the assumption that correction factors may be compounded multiplicatively are in reasonable agreement with those obtained experimentally. In fact, on the scale of Fig. 6.1 computed and experimentally determined coefficients would be quite indistinguishable. This result might have been anticipated if, as previously, we attribute changes in flow coefficient with pipe diameter to be largely a consequence of alterations in the degree of contraction immediately upstream of the nozzle—since this effect, by comparison with other separation phenomena, could be expected to become increasingly independent of R as R itself increases, so that, ultimately, $Z_{RD} - Z_R$ would be approximately independent of R. Again, agreement between the "reconstituted" and the experimental flow characteristics could be expected to improve as m decreases, since when m is small, accelerations (and thus inertia forces) are large in comparison with viscous forces (as enhanced by the presence of the walls), with the consequence that the flow pattern (including any separations inherent therein) tends towards the potential form and to become less dependent on the Reynolds number.

On the other hand, large errors are involved if coefficients calculated on the basis of multiplicative compounding of the correction coefficients are used to estimate the value of the flow coefficients when pipe-wall taps are used. This is evident from Fig. 10 which shows typical "reconstituted" and experimentally determined flow characteristics of metering nozzles with pipe-wall taps. However, the fact that such discrepancies occur is by no means surprising: indeed it would be remarkable if matters were otherwise, since theroetical considerations give no reason for the belief that the effects of changes in R, D, δ_1 and δ_2 can render $Z_{RD\delta_1\delta_2} - Z_{RD}$, independent of R and D. On the other hand, as m decreases the flow pattern, both within and upstream of the nozzle, becomes less dependent on viscous forces, and rather better agreement between the experimental and reconstituted characteristics ensues.

Errors in the flow coefficient as calculated, or "reconstituted" from equation (6) could, conceivably, be reduced by re-defining α_o as being the coefficient relating to a standard system other than a corner tapped system in which R and D have those (extreme) values which result in α being sensibly independent of these variables. However, even if this were so, there would still be a strong case against adopting, as a standard system, any system in which the flow coefficient is dependent on the Reynolds number; since, in general, the flow coefficient cannot be experimentally determined to the same high degree of accuracy as when its value is independent of the Reynolds number of the flow.

In fact, if adopted, the practice would result in the probable error in the reconstituted value of α in regions of high R being greater than the error associated with the experimental values in this region.

A.G.A.—A.S.M.E. Orifices

To what extent the flow coefficient for vena-contracta and flange tapped orifices can be derived from the "standard" corner tapped coefficient α_o and multiplicative compounding of the operational correction factors k_R, k_D, k_{δ_1}, k_{δ_2} can be ascertained in the manner previously adopted for nozzles i.e., by "reconstituting" the α versus R characteristics from a knowledge of α_o (for this purpose taken at log $R = 6$ and $D = 10$ in), k_R and $k_{\delta_1} k_{\delta_2}$ (say) for vena-contracts taps, and α_o, k_R and $k_{\delta_1}' k_{\delta_2}'$ (say) for flange taps, e.g.: if $m = 0.4225\ \alpha_o$ would be taken from point A on Fig. 8.1, k_R (for various values of R) derived from curves ① on Fig. 8.1, k_D derived from points such as B_1, B_2, B_3 on Fig. 8.1 and $k_{\delta_1} k_{\delta_2}$ and $k_{\delta_1}' k_{\delta_2}'$ from points C and C' on Figs. 8.2 and 8.3 respectively: values of k_R, k_D, $k_{\delta_1} k_{\delta_2}$, $k_{\delta_1}' k_{\delta_2}'$ so computed, are shown in Fig. 11.

In so far as reconstituted corner-tapped coefficients are concerned, calculations show that—as with nozzles—the

reconstituted coefficients at low values of m and high values of R are in good agreement with experiment.

On the other hand at values of $m > 0.25$ there is considerable discrepancy between the reconstituted and the experimental values of the corner-tapped flow coefficient (see Fig. 12). However, recent work in the United Kingdom[19] on the precision calibration of the almost identical I.S.O. orifice (as specified in ref. 1) gives rather different results: on analysis it shows that, in so far as corner-tapped orifices installed in 2 in. and 6 in. diameter mains are concerned, the operational correction factors k_R and k_D can be multiplied together to give a reconstituted coefficient which is in good agreement with experiment for area ratios covering the range $0.20 < m < 0.70$. Here, it is interesting to notice that both German[4] and I.S.O.[1, 2] Standard Codes for Fluid Metering assume the flow coefficients appropriate to corner-tapped orifices conform to equation (6), even though the literature does not appear to report direct experiments to prove this point.

Thus the only comprehensive study of the effect of varying pipe diameter appears to be that due to Witte,[20] whose reported experiments are in a range of Reynolds number in excess of that for which α is a function of R.*

Again, as with nozzles, we notice very considerable deviations between the reconstituted and the experimental flow characteristics when vena-contracta taps are used, especially when R is small and m is large (see Fig. 12); so indicating that $Z_{RD\delta_1'\delta_2'} - Z_{RD}$ is predominantly a function of the Reynolds number R. Similar remarks apply to coefficients relating to flange tapped installations except that, in this case, agreement is reasonable when D is large, since the pressure tappings are then not far removed from the corner positions themselves.

Other Cases

Following on the above discussion it is not difficult to cite many other cases of constrictive flow where conditions are such as to render it doubtful whether or not equation (6) can be satisfied: however, the extent of the discrepancy between the computed flow coefficient (based on the choice of one coefficient as standard and the compounding, by multiplication, of operational correction factors) and the experimental value thereof cannot be discussed due to lack of precise experimental data on the systems concerned.

However, in a few cases the literature on metering devices provides sufficient data to permit numerical checks being made.

Thus, if we consider flow through an upstream corner-tapped sharp-edged orifice or short-radius parallel throated nozzle of *I.S.O.* form installed at the exit of a long straight main, the results of experiments by Stach[21] show good agreement between the experimental value of the coefficient and the value calculated from the formula

$$\alpha = k_E k_R k_D \alpha_o \qquad \ldots . (54)$$

where, α_o is the "standard" flow coefficient relating to a corner tapped orifice or nozzle installed in the body of a main of diameter equal to or greater than 12 in. working at Reynolds numbers in excess of 10^6.

$k_R = \alpha_R/\alpha_o$, $k_D = \alpha_D/\alpha_o$, where α_R and α_D are coefficients for orifices and nozzles installed in the body of a main in which $R \gtrless 10^6$, $D \geqslant 12$ in. and $R \leqslant 10^6$, $D \lessgtr 12$ in respectively.

$k_E = \alpha_E/\alpha_o$ where, α_E is the flow coefficient of a corner tapped orifice or nozzle fitted at the exit extremity of a main of diameter $D \geqslant 12$ in. for a flow of Reynolds number $R \geqslant 10^6$.

* The experimental data on which these European codes are based is probably more accurate than the A.S.M.E. data which has been used in this analysis. However, the European data refers almost entirely to corner tapped installations of metering orifices and is therefore not so generally useful as the American data where analytical discussions on the flow coefficient are concerned.

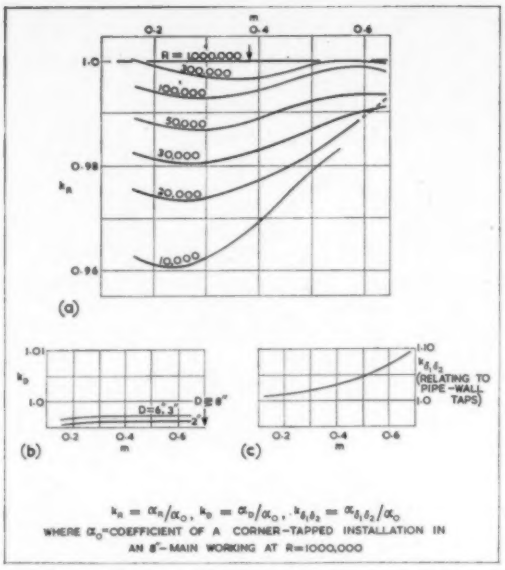


Fig. 9. A.S.M.E. nozzle: operational correction factors k_R, k_D, $(k_{\delta_1}k_{\delta_2})$.

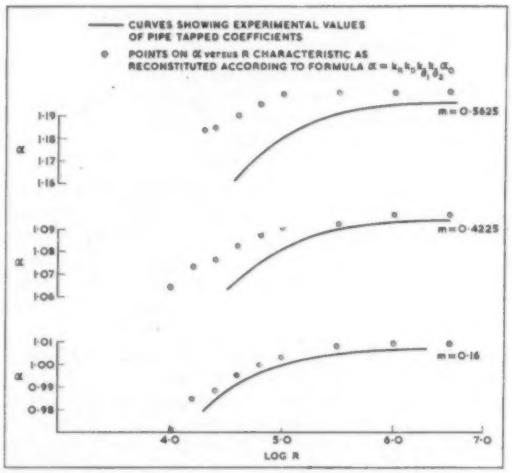


Fig. 10. A.S.M.E. nozzle: experimental and reconstituted values of α *for a pipe-wall tapped installation in a 3-in. main.*

On the other hand, for flow through the same throttling devices installed at the entrance to a main, Stach's experiments reveal very large discrepancies between the experimental coefficient and the value calculated from the formula

$$\alpha = k_I k_R k_D \alpha_o \qquad \ldots . (55)$$

where α_o, k_R and k_D have the same meaning as before, but where $k_I = \alpha_I/\alpha_o$ where α_I is the coefficient of a (downstream) tapped orifice or nozzle fitted at the entrance to a main of diameter D equal or greater than 12 in. and where the flow is at Reynolds numbers in excess of 10^6. The discrepancy between the actual and reconstituted coefficients is particularly noticeable at low Reynolds numbers; in particular, for the case of nozzles, coefficients computed from equation (55) indicate decreasing values of α with increasing values of R whereas in practice the opposite tendency is apparent.

Data are also available for flow through I.S.O. orifices in

the presence of pipe constrictions or expansions immediately upstream or downstream of the throttling device.

Thus the experiments of Ruppel and Jordan[22] indicate that, where a constriction follows an orifice only small changes are apparent in the flow coefficient and that the flow coefficient itself can be expressed as the product of the coefficient relating to flow in an unobstructed main ($k_R k_D \alpha_o$) and an operational correction factor (independent of R and D) to take into account the presence of the downstream contraction. The same remarks apply to installations with contractions immediately upstream of the metering device, providing $m \lesssim 0.5$.

In the case of pipe expansions however, the problem is much more involved since detachment of the boundary layer within the expansion piece gives rise to severe eddying and a large "scatter" in the observations which determine the α versus R characteristic: it is in fact one of the least satisfactory arrangements of a metering device, particularly when the expansion piece precedes the orifice with $m \gtrsim 0.1$: the multiplicative compounding of k_R, k_D, α_o and an operational correction factor (to take into account the presence of the expansion-pieces) is, in this case, quite inadmissible.

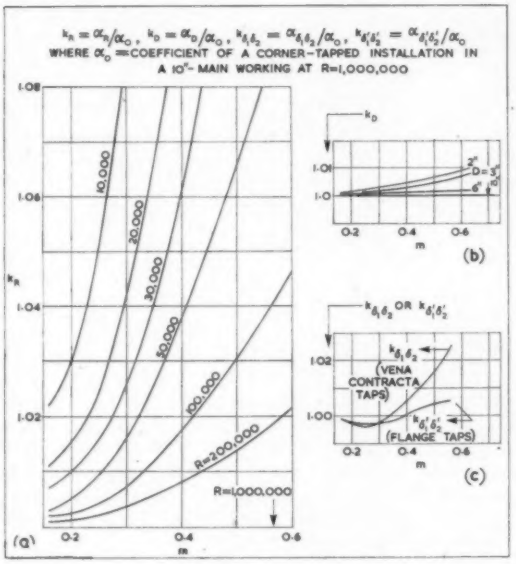


Fig. 11. A.G.A.-A.S.M.E. orifice: operational correction factors k_R, k_D, *etc.*

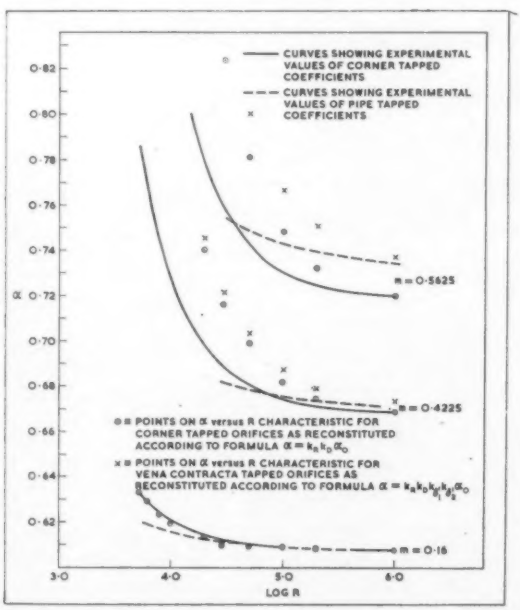

CURVES SHOWING EXPERIMENTAL VALUES OF CORNER TAPPED COEFFICIENTS
CURVES SHOWING EXPERIMENTAL VALUES OF PIPE TAPPED COEFFICIENTS
m = 0·5625
m = 0·4225
m = 0·16
o = POINTS ON α versus R CHARACTERISTIC FOR CORNER TAPPED ORIFICES AS RECONSTITUTED ACCORDING TO FORMULA $\alpha = k_m k_D \alpha_o$
x = POINTS ON α versus R CHARACTERISTIC FOR VENA CONTRACTA TAPPED ORIFICES AS RECONSTITUTED ACCORDING TO FORMULA $\alpha = k_m k_D k_{b_1} k_{b_2} \alpha_o$
α
LOG R

Fig. 12. A.G.A.-A.S.M.E. orifice: experimental and reconstituted values of α *for corner and vena-contracta tapped installations in a 3-in. main.*

Finally, it is interesting to consider the extreme case when m itself is regarded as an operational variable having a value different from that in a standard system for which (say) $m = m_o = 0.36$. Thus, if α_o is the value of the flow coefficient for a corner tapped A.G.A.-A.S.M.E. orifice in a standard system for which $m = m_o = 0.36$ and $D = 10$ in. we find wide differences between experimental values of the flow coefficient and reconstituted values based on the equation

$$\alpha = k_m k_R k_D k_{b_1} k_{b_2} \quad \ldots . (56)$$

—where k_m is the operational correction factor which takes into account variations in the value of m (when this differs from the value $m = 0.36$) and where k_R, k_D, k_{b_1}, k_{b_2} have the same meaning as before. Thus, if $m = 0.25$, $R = 2.10^4$, $D = 10$ in. and corner taps are used, (so that $k_{b_1} k_{b_2} = 1$), the difference between the actual flow coefficient and that reconstituted from equation (56) amounts approximately to 6% of α_o.

Conclusions

From the above discussion it would appear that we are justified in assuming that the operational correction factors may be compounded from their product only if:

(1) Evidence is available to substantiate that the effects of changes in the values of the condition variables $a, b, c \ldots m \ldots n$ are such that a generalised form of Equation (42), with $\dfrac{k_{abc\ldots n}}{k_a k_b k_c \ldots k_n} = 1$, is satisfied for all values of $(a - a_o)$, $(b - b_o)$, $(c - c_o) \ldots$ a relation which, in practice, usually amounts to satisfying the requirement that $\Sigma(Z_m - Z_o) = Z_{abc\ldots m\ldots n} - Z_o$, *or if*

(2) the fluid mechanics of the problem reveals that the above relation is satisfied for particular (rather than general) values of $a, b, c \ldots$. (The satisfaction of this condition however does not justify Equation (6) in the general case, but only confirms the truth of the relation for particular values of $k_a, k_b, k_c, \ldots$) *or if*

(3) direct experimental evidence justifies multiplicative compounding of the operational correction factors.

Since general considerations can only be expected to supply the requisite information in special cases and since a rational theory is not yet available for presenting the flow pattern of a constricted sream, the main justification for the multiplicative principle must stem from the results of experiments designed specifically with this purpose in view.

Evident though this may be, it is surprising that the literature of the subject so often assumes, almost axiomatically, the validity of the multiplicative principle—in effect we often find acceptance of the principle by implication rather than by any process of logical deduction. E.g., in the I.S.O.[1, 2] Standard Code for Fluid Metering a number of operational correction factors are quoted (including k_R and k_D defined as above), but no observations are made concerning the extent to which these may be combined generally, or in certain special combinations; neither is any indication given as to the probability of there being a systematic error (as distinct from observational errors of experiments for determining each of the operational correction factors) when these factors are so combined.

In acceptance and performance testing of hydraulic

equipment where metering apparatus has often, of necessity, to be installed under non-standard conditions, the above considerations can be of considerable importance. In effect, they rule out high-accuracy acceptance testing in all cases of non-standard construction and/or installation of the pressure difference device unless there is experimental evidence to show how modifications from the standard can be taken into account in assessing the flow coefficient; or unless experiments have been previously conducted to determine the flow coefficient relevant to prevailing conditions. However, this latter requirement does not, necessarily, imply that full scale calibrations of the metering device are essential, since, in many cases, the requisite coefficients may be obtained, with sufficient accuracy, from experiments on models. Similar remarks apply to pressure inferential metering, in the process industries, except that, in these cases the scale of the installations are usually much smaller, so that calibration *in situ* of non-standard metering systems is often a quite practicable proposition.

APPENDIX

The relation $\alpha\delta_1\delta_2 = k\delta_1 k\delta_2 \alpha_o$ for pipe-wall tapped metering nozzles

Consider, as in Fig. A1, a main of diameter D, conveying a mass flow G (at Reynolds number $\geq R_e$) of fluid density γ to a nozzle having a throat area A_o, with consequent wall-pressures P_1 and P_2 immediately upstream and downstream of the nozzle, and P_1' and P_2' at positions respectively $1D$-upstream and $0.5D$-downstream of the nozzle entrance section—so that $(P_1 - P_2)$ and $(P_1' - P_2')$ are the pressure differences across the corner and pipe-wall taps respectively.

Then

$$\alpha^2_O = \frac{G^2}{A_o^2 2\gamma(P_1 - P_2)} \quad \ldots.(A1)$$

$$\alpha^2\delta_1\delta_2 = \frac{G^2}{A^2_o 2\gamma(P_1' - P_2')} \quad \ldots.(A2)$$

$$\alpha^2\delta_1 = \frac{G^2}{A^2_o 2\gamma/(P_1' - P_2)} \quad \ldots.(A3)$$

$$\alpha^2\delta_2 = \frac{G^2}{A^2_o 2\gamma(P_1 - P_2')} \quad \ldots.(A4)$$

$$k\delta_1 = \alpha\delta_1/\alpha_o \quad \ldots.(A5)$$

$$k\delta_2 = \alpha\delta_2/\alpha_o \quad \ldots.(A6)$$

where $\alpha\delta_1$ and $\alpha\delta_2$ are the flow coefficients when only δ_1 and δ_2 respectively differ from their values in the standard (i.e. corner tapped) system; and where all the above equations follow directly from the definitions of the quantities α_o, $\alpha\delta_1\delta_2$, $\alpha\delta_1$, $\alpha\delta_2$, $k\delta_1$ and $k\delta_2$ themselves.

Furthermore, conditions are such that, numerically,

$$P_1' - P_2' = (P_1 - P_2) - (P_1 - P_1') + (P_2 - P_2') \quad \ldots.(A7)$$

$$P_1' - P_2 = (P_1 - P_2) - (P_1 - P_1') \quad \ldots.(A8)$$

$$P_1 - P_2' = (P_1 - P_2) - (P_2 - P_2') \quad \ldots.(A9)$$

Elimination of $(P_1' - P_2')$, $(P_1' - P_2)$, $(P_1 - P_1')$, $\alpha\delta_1$ and $\alpha\delta_2$ from equations (A1) to (A9) then gives

$$k^2\delta_1 k^2\delta_2 = \frac{\alpha^2_o}{\alpha^2\delta_1\delta_2} + \left(\frac{P_1' - P_2}{P_1 - P_2}\right)\left(\frac{P_2 - P_2'}{P_1 - P_2}\right) \quad \ldots.(A10)$$

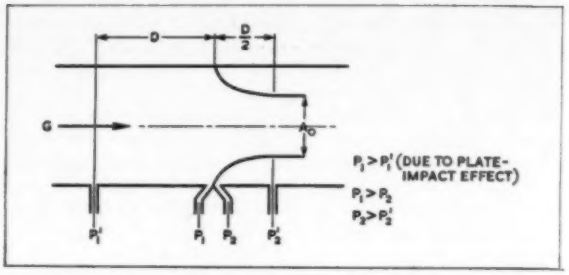


Fig. A.1. Definition sketch relating to corner and pipe-wall nozzle-taps.

which, if both $(P_1' - P_1)/(P_1 - P_2)$ and $(P_2 - P_2')/(P_1 - P_2)$ are small compared with unity, reduces to

$$\alpha\delta_1\delta_2 = k\delta_1 k\delta_2 \alpha_o \quad \ldots.(A11)$$

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N.B.: The orifice-coefficient data given in the A.S.M.E. and A.G.A. Codes of Practice (refs. 5, 7 and 8) and in the Joint A.G.A.-A.S.M.E. Report (ref. 18)—from which these Codes originated—is based on the results of experiments described in this paper (ref. 13). Recently a fifth (1959) edition of the A.S.M.E. publication has become available and the A.G.A. has issued a Gas Measurement Report No. 3 (dated 1955). However, over the range of pipe diameters and Reynolds numbers discussed in this paper the flow-coefficients given in these newer publications are as recommended in earlier issues.

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Radioactive Tracing of Phenol Losses in Oil Refining

Continued from page 713

than the earlier ones, and that the residual oil, which should contain no phenol, retained some Br^{82} compounds. In this case the o-bromphenol had been prepared by a relatively crude fractionation of the irradiated material after removal of inorganic bromine, and it was quite likely that radioactive impurities of lower volatility than o-bromphenol, e.g., dibrombenzene, remained in the residual oil. For Experiment 2, the o-bromphenol was more carefully fractionated, but in this case also a considerable non-phenolic but radioactive residue was found in the oil. For Experiment 3, therefore, the o-bromphenol was purified with even more care. The irradiated material was fractionally distilled through a column of 5 to 6 theoretical plates at a reflux ratio of 5:1 and collected at a rate of 4 ml a minute; the distillate was dissolved in ether, carrier brombenzene added and the bromphenol extracted five times with caustic soda solution. The alkaline solution was acidified and the liberated phenol extracted with ether, the ether solution washed with water and dried over anhydrous sodium sulphate, α-methyl naphthalene was then added (its boiling point is above that of o-bromphenol) and the ether evaporated. The resulting mixture was then carefully fractionated at reduced pressure (3 mm) and a fraction of the first 60% distilled was used for the phenol-oil distillation experiments. Determination of the specific activity indicated that 16.3% of the total Br^{82} was present as bromphenol and that the brombenzene content was negligible; less than 0.4% Br^{82} activity was present as brombenzene.

When this highly purified material in o-bromphenol-oil mixtures was distilled (Table AIV, Experiment 3) the o-bromphenol was removed at the same time as the phenol. The radioactivity in the residual oil fraction corresponded to 0.20 ±0.15% phenol, which can be compared with 0.042 ±0.004% phenol by chemical analysis. The limits of error in the activity measurement were due to the fact that the activity, 3.3 counts/min., was very low; in fact, about one-third of the natural background of the "liquid" counter. It was also noted (Table AIV) that the first phenol fractions contained slightly more activity than the later runnings, although this effect was less marked with decreased distillation pressure. This was thought to be due to azeotrope formation. Since the full-scale plant has an efficiency of only 1-2 theoretical plates and operates at about 2 mm, compared to the laboratory experiments at 4-7 mm pressure and an efficiency of 5-10 theoretical plates, it was believed that this azeotrope effect would be less noticeable under plant operating conditions.

From these laboratory distillation and extraction experiments it was concluded that o-bromphenol would be a satisfactory tracer for phenol in a phenol extraction plant, provided that the active o-bromphenol material was sufficiently pure.

(5) *Preparation of Radioactive o-bromphenol for the Plant Experiment*

One hundred grams of pure o-bromphenol in a polyethylene bottle contained in a metal outer container were irradiated for 14 hr at a neutron flux of 1.3×10^{13} neutrons/cm² sec., and then kept in a shielded area for 14 hours to allow most of the Br^{80} to decay. The bottle was then transferred to a working space shielded by 10 cm of lead.

Using remotely operated tools, a tube was inserted into the bottle and the contents sucked into a distillation flask. Carbon tetrachloride washings of the bottle were added to the flask and the carbon tetrachloride and some of the some of the low boiling impurities distilled off at atmospheric pressure. The pressure was now reduced to 7 mm and the o-bromphenol (B.P. 70-72°C) fractionated, using a reflux ratio of 2:1 and collecting at 1 ml/min. The distillate was then added to 100 ml CCl_4 in a separating vessel, and the phenol extracted with 5N caustic soda solution, leaving the neutral impurities in the organic phase. The solutions were stirred by air injection after three washings with CCl_4. The aqueous solution was next acidified with concentrated hydrochloric acid and the heavy phenol layer which separated allowed to run into another still for fractionation as before. The final product was run into a polyethylene bottle and capped for transport to the refinery. The yield was 62 g and the radiochemical yield 11.3% (370 mc), corresponding, after correction for chemical yield, to 18.2% of the total Br^{82} in the form of o-bromphenol. A small sample was taken for absolute assay of the Br^{82} content.

The complete purification process was performed in a remotely controlled apparatus on a well-ventilated bench fitted with a 10-cm lead shield. The controls for the services (air, vacuum, etc.) were situated outside the lead wall, which was also fitted with a 10 cm thick lead glass window so that direct observation of the apparatus was possible. The whole process of purification from the removal from the reactor to the completion of the chemistry took 8 hr, and the radioactive o-bromphenol was ready for injection into the plant 11.5 hr after its removal from the reactor.

SIEVE TRAYS FOR DISTILLATION COLUMNS

Some details of the design and operating experience of a simple and inexpensive contacting means

by BOHUSLAV MELICHAR*

TO evolve the best design of a given piece of apparatus it is always wise to draw upon as much past experience of the particular equipment as possible. The purpose of this article is to present the results of such experience with regard to perforated plate distillation columns.

A design of small-diameter sieve tray is illustrated in Fig. 1. The overflow device consists of a vertical tube, the top edge of which protrudes above the bottom surface and thus determines the level of the liquid in the bottom, while its lower end is immersed in the cup which functions as the hydraulic closure proper. The cup is constantly filled with the liquid, is 35 to 45 mm deep and should have a cross-section at least twice that of the immersed tube. The distance between the bottom edge of the tube and the cup bottom should be approximately one-quarter of the tube diameter. With small tubes this distance should amount at least to 20 mm to prevent clogging of the overflow tube. The cup base is often provided with a small hole, so that the liquid will drain from the plate and not remain in the cup once operation has ceased. With columns of greater diameter each tray is provided with two or more overflow tubes.

With most modern designs overflow edges have replaced the overflow tubes. On the opposite side of the overflow edge an intake edge of the same length is fitted (Fig. 2). With this arrangement of tray a uniform flow of liquid has been attained on its entire area, so that proper boiling of the liquid is ensured.

Reducing Entrainment

The increase of vapour velocity between the separate trays will increase also the output of the column, but entrainment of the liquid by the vapour stream flowing to the next tray above will be also increased, which affects adversely the tray efficiency. Various designs, many of them patented, for dispersing and separating the droplets entrained in the vapour stream, have therefore been evolved. These designs may consist of layers of Raschig rings of separating sheets mounted between the trays.

One such design is illustrated in Fig. 3. The alcohol vapours passing through the tray strike against the perforated plates which are mounted between the vapour space between trays and above the liquid level. Through impact on the intermediate trays the vapours give up the major portion of entrained liquid before passing through the perforations of a sieve tray. The construction of this equipment, however, is difficult and costly and it is therefore seldom used. The entrainment of the liquid at higher vapour velocities can be reduced simply by increasing tray spacing.

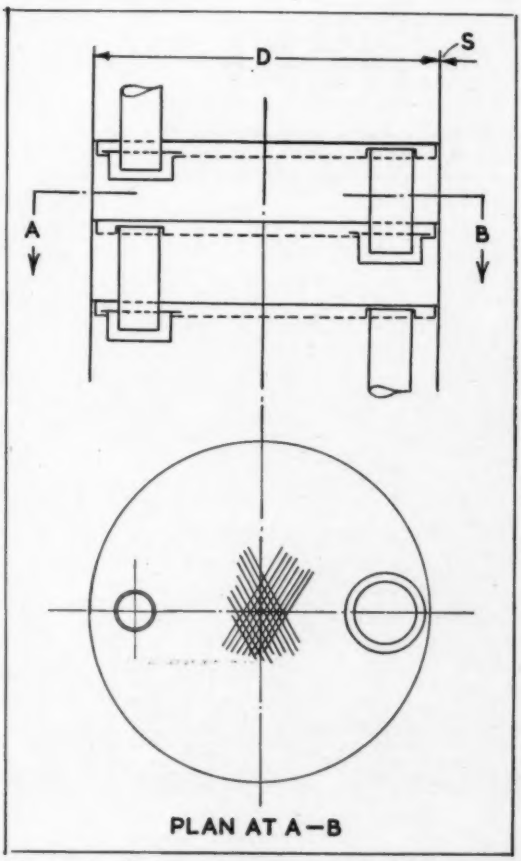


Fig. 1. Small-diameter sieve tray with single overflow branch.

* Ing. Bohuslav Melichar is employed at the Skoda Works, Czechoslovakia, and is now in the Research and Development Department there. He is also a lecturer at the Technical College in Brno.

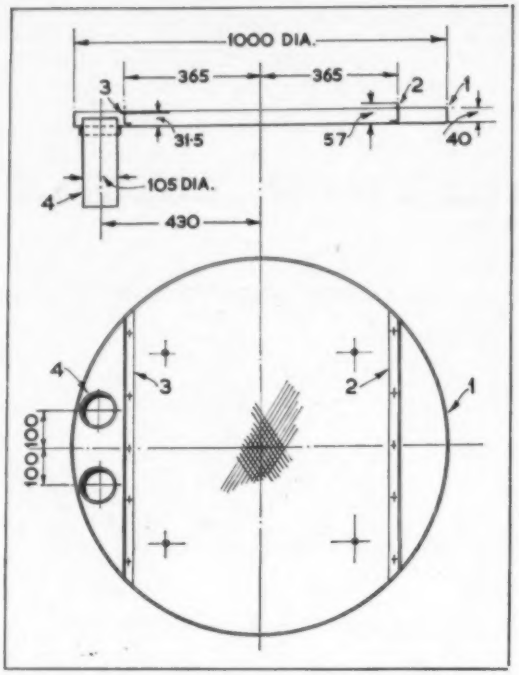


Fig. 2. Sieve tray with uniform overflow. (Dimensions in mm.). 1. Sieve section. 2. Intake weir. 3. Overflow weir. 4. Overflow tubes (dimensions in mms).

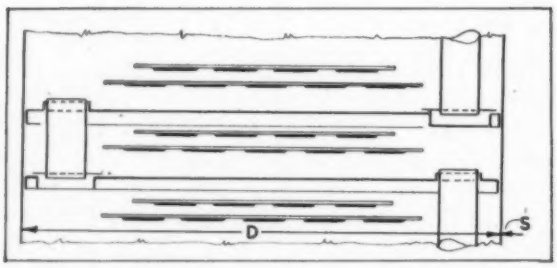


Fig. 3. A sieve tray with entrainment separation plates

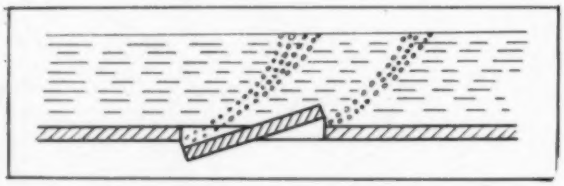


Fig. 4. Detail of sieve tray with longitudinal perforations.

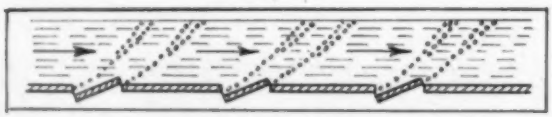


Fig. 5. Liquid flow on sieve tray with longitudinal perforations.

Perforation Sizes

The hole diameters of 2.5 to 3 mm. are now commonly used, but after long operation the holes become enlarged by the vapour stream. The pitch of the perforations is usually 7 to 9 mm. The tray edge is fitted with a flange deflected upwards or downwards, which is used for riveting or soldering the tray to the copper border of the column. Sieve trays are generally made of copper or brass sheet, the holes are punched mechanically, and most new designs have their holes arranged in equilateral triangular pitch. The free area provided by the holes amounts approximately to 5 to 15% of the total area of the column cross-section. The mean velocity of vapours is usually about 6 m/sec. At lower vapour velocities the liquid may not remain upon the tray, but will flow instead through the holes. In addition to the vapour velocity through the holes, the head of liquid on the tray, the hole diameter, the tray thickness, liquid surface tension and viscosity are all important. The relation between the hole diameter and the minimum flow velocity at which the liquid is still retained on a tray is given by

$$d = \left\{\frac{13.9\mu\,(h+b)\,((h+b)\rho_l/\rho_v)^{\frac{1}{2}}}{0.786\,(h+b)\rho_l - 0.08\,\rho_v\,v_0^2}\right\}^{\frac{1}{3}} \qquad \ldots\ldots(1)$$

where d = the hole diameter, m;
h = the height of liquid on tray, m;
b = the plate thickness, m;
μ = viscosity, kg . s/m^2;
v_0 = the vapour velocity, m/s;
ρ_l = specific density of liquid, kg per m^3; and
ρ_v = specific density of vapours, kg per m^3.

According to Anoshin[2], who investigated experimentally the vapour velocity at which the liquid is still kept upon a tray

for $d = 2.5$ mm, the $V_0 = 2.0$ m per sec.
and for $d = 4.0$ mm, the $V_0 = 8.0$ m per sec.

These results agree reasonably well with calculated velocities.

Simple Performance Checks

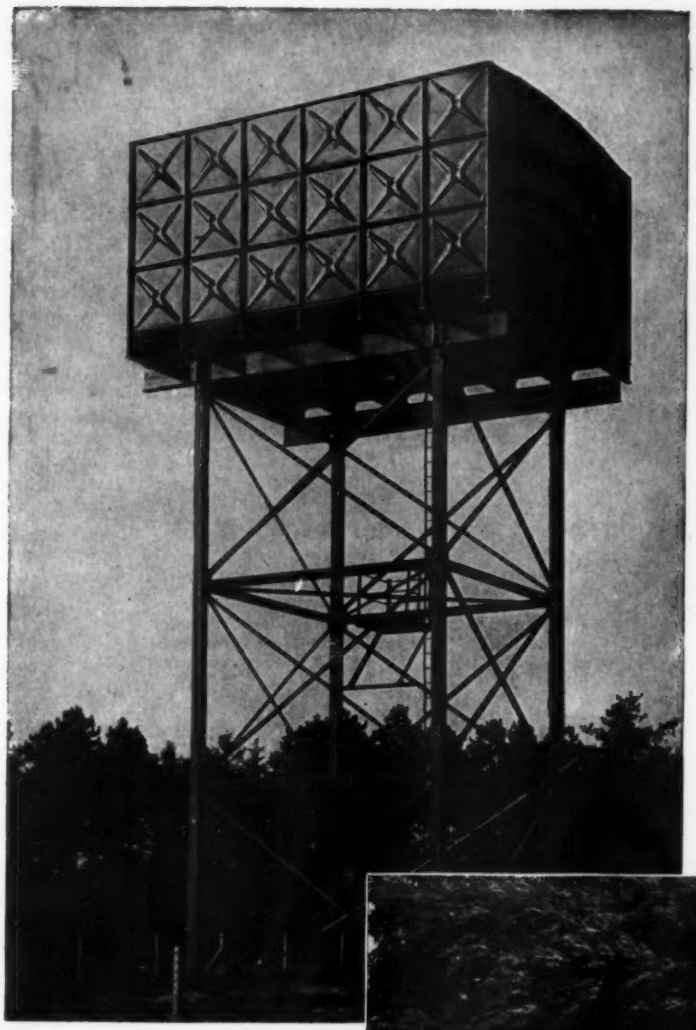
The output of a column with sieve trays must be sometimes checked in operation and determined by a simple calculation. A formula suggested by A. L. Malchenko can be used for this purpose. This takes into consideration not only the operation of the column proper, but also the available dephlegmator surface, the capacity of the boiling pan and quality of crude alcohol. When processing crude alcohol from molasses the formula is written in the following form:

$$M = (KF \pm 1.5\,n/\,.\,K_1K_2)\ \text{dkl per 24 hr.}$$

The term $(KF \pm 1.5\,n)$ expresses the output of the column, where F is the superficial cross-section of the column in sq. m., K is the factor expressing the withdrawal of alcohol per sq. m. of the column cross-section in dkl of absolute alcohol per hr. This varies according to the type of tray and the cross-section of the column.

The values of the factor K are given in Table I.

The calculated output KF dkl per hr relates to a standard column with 42 trays. With a number of trays in excess of 42 the output of the column is increased by 1.5 dkl per hr per additional tray. With lesser number of trays the output is reduced by the same amount. Thus n is the number of trays less than or in excess of the number of bottoms of a standard column. The value n, however, must not exceed 7. The effect of the dephlegmator area (as well as of the reflux) is taken care of by the factor K_1. The area of the deflegmator must amount to 0.6 sq. m per 1 dkl per hr of the column output. In such instance, $K_1 = 1$. Otherwise the dephlegmator area may be such that either K_1 is less or greater than unity. The values of the factor K_1 are given in Table II.



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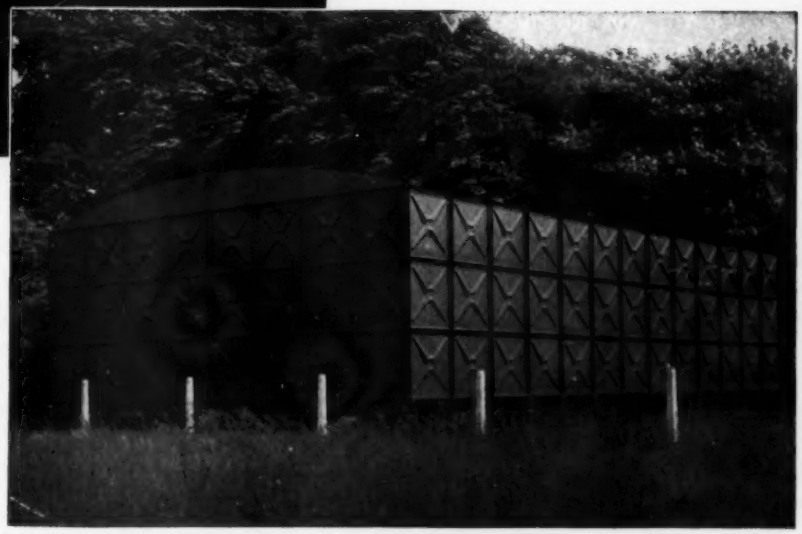

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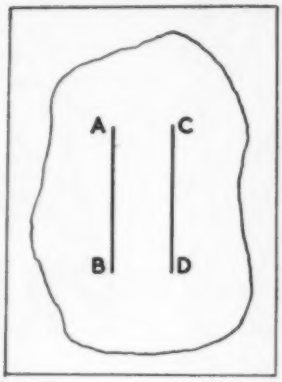


Fig. 6. Position of slots in sieve tray before twisting.

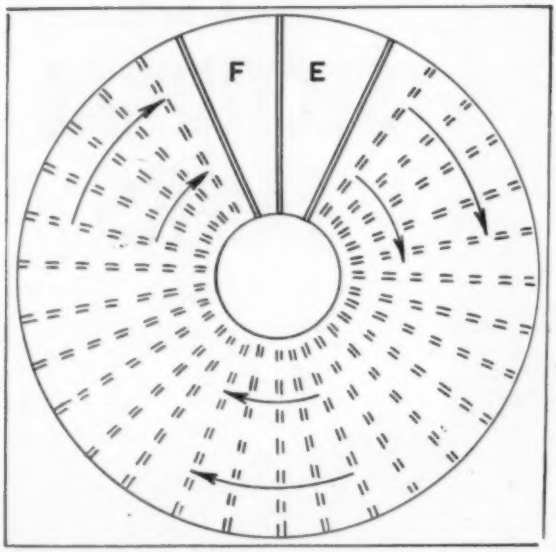


Fig. 7. A sieve tray with circular direction of liquid flow.

With further increase in dephlegmator area, the coefficient K_1 does not change because a large reflux flow cannot pass through the overflow branches and will hamper the operation of a column. The product $(KF \pm 1.5\,n)\,K_1$ expresses, therefore, the output of the apparatus in dkl per hr. For the purpose of calculation of the output M in dkl per 24 hr, the product $(KF \pm 1.5\,n)\,K_1$ must be multiplied by the number of hours of withdrawing refined alcohol per 24 hr. This number is called factor K_2 and it can be assumed that $K_2 = 24$, where y is the efficiency of the apparatus, i.e., a ratio of time of drawing off of refined alcohol to the time required for the entire operating cycle of the apparatus. The value y depends on the capacity of the boiling pan. The higher the capacity of the boiling pan, the greater relatively the time of drawing-off of refined alcohol. The boiling pan capacity is approximately proportional to the duration of one operating cycle. Thus, factor K_2 given in Table III relates to the duration of the operating cycle. When processing crude alcohol produced from grain or potatoes the output of the apparatus is increased, since the impurities are more easily separated during refining. A factor 1.1 is incorporated into the formula; hence

$$M = 1.1\,(KF \pm 1.5\,n)\,.\,K_1K_2 \text{ dkl per 24 hr} \quad \ldots . (2)$$

The output of the apparatus calculated according to Equations (1) and (2) represents a mean value and can be increased by 25% or even more, given careful operation of the equipment.

Experiences of Sieve Trays

Ch. Mariller[3] has compared the performance of a large number of batch columns fitted with sieve trays which have operated in France and has found that each hl of refined alcohol produced hourly requires the following column cross-section area:

Output of apparatus hl/24 hr	Column cross-section sq.dm	Output of apparatus hl/24 hr	Column cross-section sq. dm
5	81.0 to 92.5	50	31.3 to 43.2
10 to 20	42.2 to 56.6	100 to 150	28.5 to 32.1

These data give a quick rule-of-thumb method of determining the required cross-section. Clearly, with increased output of the apparatus the number of sq. dm of the column cross-section per 1 hl of produced refined alcohol is reduced. Table IV gives the dimensions of batch distillery columns fitted with sieve trays produced before the war by the German firm Pampe. The outputs of the columns are given for production of refined alcohol in lit. per hr with good quality of the refined product and at alcohol content of minimum 96% by volume. Perforated trays with large holes can be used in distillery columns for worts of molasses and also of starchy raw materials. Thus according to Gladilin[4] perforated trays with 3375 holes 11 mm in diameter were used in a column 1980 mm in diameter, fitted with 22 trays made of copper plate 5 mm thick. The wort level on a tray is 27 mm and each tray is reinforced by six radial ribs which transmit the load to the edge and to the central column shell. The tray spacing is 559 mm above each tray has two oval manholes disposed opposite each other. The hydraulic closure is formed by a cup of spherical shape without a hole.

The large tray spacing permits high vapour velocities without causing serious liquid entrainment.

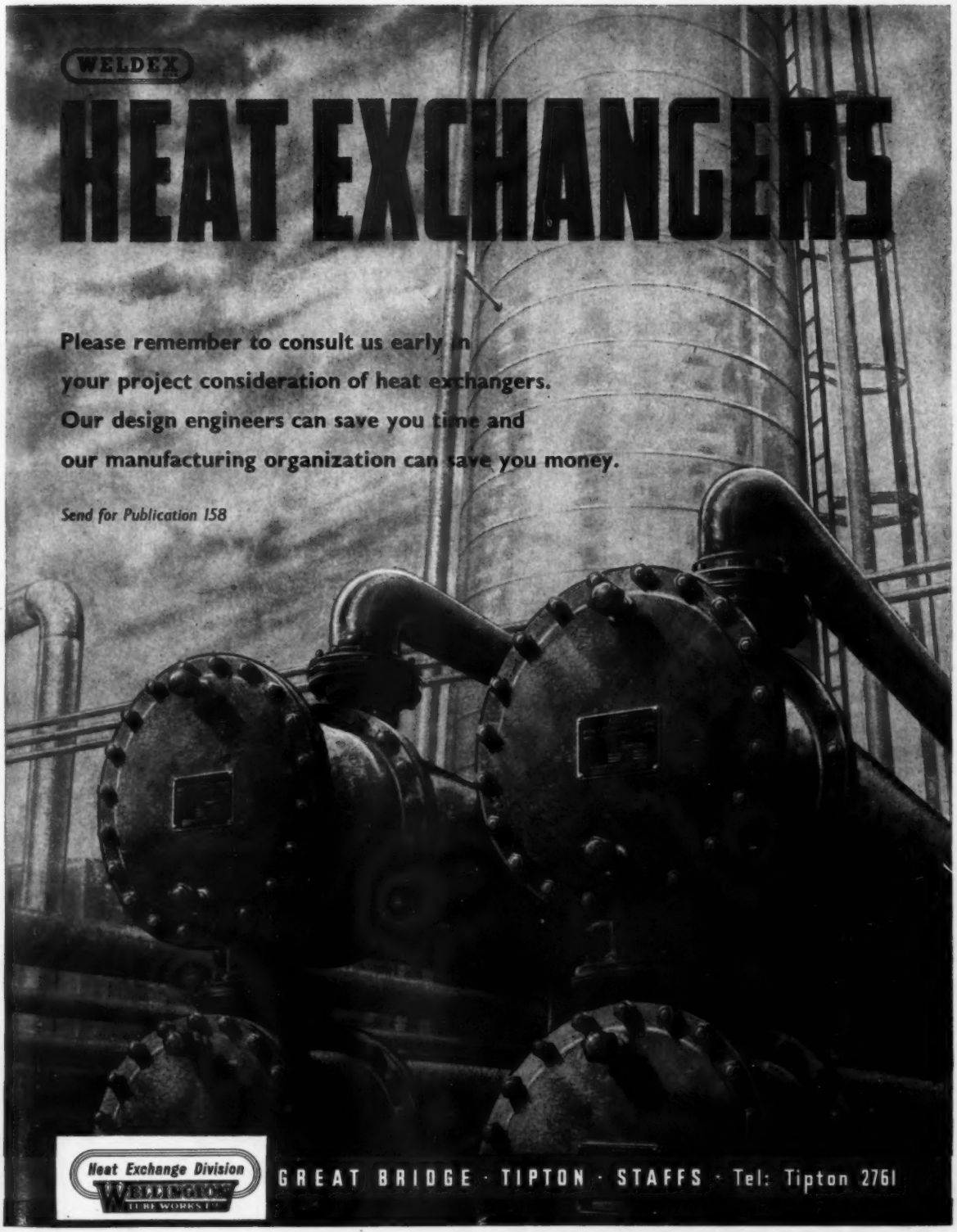
Such experience has been fully used in the reconstruction of a distilling column in the Kojetin distillery in Czechoslovakia. The existing sieve trays in this case were replaced by sieve trays with larger holes. This measure increased the output from 230-250 to 330-350 hl of absolute alcohol per 24 hr.

Material Requirements

Sieve trays require much less material than bubble-cap or other similar trays and they are, therefore, less expensive The following example shows how their use can save material.

A distilling column for producing 840 hl of absolute alcohol per 24 hr from starchy worts with bubble-cap trays had a diameter of 2800 mm and weighed 26,000 kg. A column with the same output, but with perforated trays with large holes, requires a diameter of 2000 mm only and weighs 12,000 kg, so that the saving in weight is more than half.

In the earlier designs the holes in sieve trays were circular, but recently different shapes of hole have been used, Fig. 4 being an example. In this tray each pair of holes is formed by two parallel cuts in the plate in such manner that one hole was above and the other below the bottom plane (Fig. 5). A piece of plate of which the bottom should be made is illustrated in Fig. 6. Two cuts are carried out in the plate in the length AB and CD which form the long sides of a rectangle. The short sides of the rectangle are formed by two bridges, AC and BD, which connect the strip with the plate. Both long sides of the strip AB and CD are then bent in such manner that one side will be above and the other below the bottom plane. The vapours rising in the column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pass through these holes and bubble through the liquid which is contained in the bottom. The direction of the vapour stream in the hole is horizontal at the beginning and then is gradually deflected in the direction of the liquid level. The effects of all rising streams upon the liquid combine to assist its flow on the tray. The direction of the liquid flow (shown in the illustrations) is determined by the position of the holes. On the tray with circular liquid flow (Fig. 7) the liquid flows to the bottom in the sector marked E and after circular flow in the direction of the arrows leaves the tray in the sector F through the overflow device and flows to the lower tray. In this arrangement of the bottom the holes are situated in radial manner and the vapours rising through the holes assist the circular flow of the liquid in the bottom.

Advantages and Disadvantages of Sieve Trays

Although simple in design, sieve trays have some disadvantages. They are, for example, very sensitive to changes of pressure. Should pressure in the bottom of the column be reduced, the liquid content of all the trays falls into the bottom of the column, so that losses can be caused by drainage into the sewer. It is recommended, therefore, to make the part of the column beneath the first tray of sufficient capacity as to hold the entire liquid load of the remaining trays.

With batch rectification columns such as are used in alcohol refineries the sieve tray column is usually mounted on a boiling pan of large capacity, so that as soon as the pressure in the column drops the combined liquid content of the trays falls into the boiling pan; there is no loss of alcohol, since the outlet cock of the boiling pan is normally closed. Another disadvantage arises from the use of small holes (2 to 3 mm) and its high hydraulic resistance. They cannot be used, therefore, for liquids from which solids (crystals) may precipitate. Trays with large holes (10 to 11 mm) can be used also in distillation of thick worts, if properly designed.

To function properly a sieve tray must be straight with the minimum possible sagging. Small-diameter trays (up to 600 mm) do not require reinforcing, but trays of greater diameter must be reinforced to prevent deflection caused both by their own weight and by the liquid load. During erection of columns such trays must be mounted horizontally, otherwise deviations from the horizontal produce an uneven level of the liquid on the tray with the consequence that vapours will flow mainly through the holes with lesser submergence. The efficiency of the tray and the operation of the column will therefore suffer.

New Type of Perforation

In the tray shown in plan in Fig. 8 the liquid flow is radial; it enters the tray in the middle in the sector marked E and flows down on the external periphery at the place marked F. The flow of the liquid on the tray takes the direction indicated. In this instance the holes in the tray are situated on concentric circles and the vapours rising through them assist radial flow of liquid.

Another advantage is that this type of hole permits greater rigidity of tray, compared with a normal straight plate. The sagging caused by tray weight and the weight of the liquid on the tray will be less and liquid will have a uniform level. Plates with such holes permit the use of thinner plate in the construction of the tray, which, in turn, reduces the weight of the entire column. These new trays are to be for the separation of liquefied gases at low temperatures, and they are not suitable for use in alcohol distilleries.

Inclined Sieve Trays

Some interesting results have been obtained with sieve trays in a reconstructed distillation column in the Krasnokam sulphite alcohol distillery (U.S.S.R.). The flow area

TABLE I—Values of Factor K

Area of column cross-section sq. m	Value of factor K dkl/h	
	Screen bottoms	Bubble-cap and tunnel bottoms
0.35	90	80
0.50	85	75
0.70	80	70
0.90	75	65
1.25 and more	70	60

TABLE II—Values of Factor K_1

Cooling surface of defleghmator sq. m per dkl/h	K_1
0.3 and less	0.5
0.4	0.66
0.45	0.75
0.5	0.833
0.55	0.92
0.6	1.0
0.65	1.04
0.7	1.08
0.75	1.12
0.8	1.16
0.9 and more	1.18

TABLE III—Values of Factor K_2

Number of hours required for distilling of the boiler pan contents	Efficiency of apparatus η_i	K_2
20	0.625	15
25	0.65	15.6
30	0.68	16.3
35	0.71	17
40	0.75	18

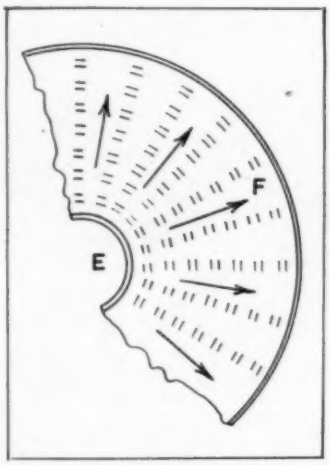

Fig. 8. A sieve tray arranged with liquid flow in a radial direction.

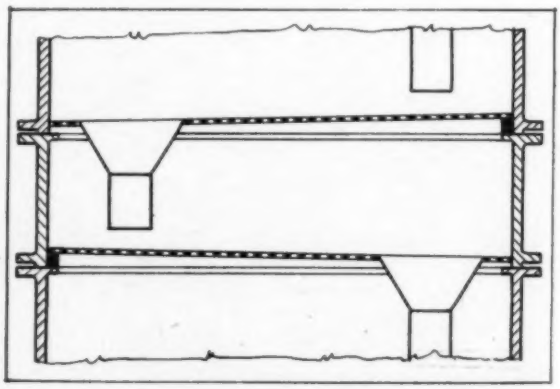

Fig. 9. An inclined sieve tray with conical inlets to overflow branches.

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TABLE IV—Outputs and Diameters of Refining Columns with Sieve Trays

Output, lit. per hr	100	150	200	300	400	500	850	1000	1200	1400
Diameter of column, mm	450	520	550	700	800	950	1215	1350	1480	1650

TABLE V—Values of Factors of Equation (4) Determined Experimentally

Tested mixture	Distance between trays mm	Level of liquid in tray mm	Factor n	Factor A
Water-air	130	12.5	3.103	2.887
	232	12.5	3.784	0.0235
	130	8.5	6.96	0.00193
	232	8.5	1.81	0.0322
Aqueous solution glycerine-air	100	8.5	3.107	0.0439
Crude alcohol-air	130	8.5	7.305	0.0107

of the sieve tray holes was increased and the design of the tray changed. The trays were mounted inclined at 1:44 slope and fitted with new overflow branches without the edges protruding above the bottom surface. The lower end of the overflow branch was neither immersed in the liquid nor was it fitted with the usual hydraulic cup type closure (Fig. 9). The funnel shape of the overflow branch prevents the vapours from entering it, and in the cylindrical section a column of liquid is formed which acts as a hydraulic closure. Since the tray is mounted at an incline and has no projecting edges at the overflow branch, the liquid on the tray forms a thinner layer than with other trays, and though it has been generally acknowledged that such trays should be mounted horizontally, the experience with this column shows that sieve trays inclined to the horizontal operate satisfactorily under heavy loads. Another advantage of inclined trays is the prevention of clogging, e.g., with gypsum. This is explained by the fact that the velocity of the wort on the inclined tray is considerably higher than with a horizontal tray, so that the precipitated gypsum crystals are carried away in the wort flow.

Among the research work carried out recently in the U.S.S.R. upon the hydraulics of sieve trays, the work of Marfenina is noteworthy. She measured the entrainment in an experimental column in which five different sieve and bubble-cap bottoms were mounted and up which air was passed. The column was 258 mm in diameter with tray spacings of 100, 130 and 232 mm, liquid depths of 8.5 and 12.5 mm, and holes of 0.8 mm diameter. The air velocity in the column varied from 0.08 to 0.7 m/sec. In order to investigate the effect of viscosity upon the droplet entrainment, the mixture of aqueous solution of glycerine and air was tested in addition to the mixture air-water; and to examine the effect of surface tension a mixture of crude alcohol with air was also tested.

It was found that the entrainment of droplets depends upon the Reynolds number calculated for the liquid phase flowing from tray to tray. This relation can be expressed by the formula:

$$m = A(\mathrm{Re}\ 10^{-3})^n \qquad \ldots . (4)$$

where A and n are factors obtained experimentally. Table V gives values of A and n for various tray spacings, liquid levels and liquid mixtures.

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[2] Anoshin, I. M. Vlijanije razmerov setčatoj tarelky na effektivnost processa rektifikaciji. *Spirtovaja promyšlennost'*, 1954, 2, 9-12.

[3] Mariller, Ch. Distillation et rectification des liquides industriels.

[4] Gladilin, N. I. *Rukovodstvo po rektifikaciji spirta*, Moscow, 1952, 305.

Expansion of Synthetic Rubber Plant at Hythe

THE plant, which first went into production in late 1958, has now had its capacity of styrene-butadiene rubber manufacture expanded to 90,000 tpa. Included in the greater capacity are facilities for making a styrene-butadiene latex of high solid content (in excess of 62%) for dispatch direct to consumer. Its main outlet is for foam rubber manufacture and the increased solids content compared with that of the S-B latices normally manufactured offers a considerable saving in transport costs.

The additional plant for producing this concentrated latex takes the dilute latex produced by the main polymerisation process and subjects it to a chilling process in a rotary drum chiller, after which the latex is further concentrated by evaporation. The chilling operation modifies the viscosity temperature characteristics of the latex without which the concentration by evaporation would not be possible. In fact, without it evaporation would produce a material of such high viscosity as to be useless for further processing. The design of this section of the plant, and its commissioning was carried out by I.S.R.'s own team of chemical engineers.

The following are some details of the extended plant:

Area of plant site	54 acres
Area covered by installations	330,000 sq ft
Initial cost of construction and equipping plant, inclusive of site clearance	£6,000,000
Storage Tank Capacities	
Butadiene	350,000 Imp. gal.
Styrene	240,000 Imp. gal.
Process oil	140,000 Imp. gal.
Antioxidant	33,000 Imp. gal.
Salt water	1,000,000 Imp. gal.
Latex	100,000 Imp. gal.
Estimated pipeline mileage within plant boundaries (all liquids)	Over 50 miles
Annual butadiene consumption	Over 60,000 tons
Annual styrene consumption	20,000 tons approx.
Oil consumption	4,000,000 Imp. gal. p.a.
Compressed air consumption	600,000,000 cu. ft p.a.

It is estimated that more than $30 million per annum are saved by this plant.

A further important point about the concentrated latex manufacture is that it will stabilise and reduce the prices of this commodity. Previously makers of foam rubber were severely handicapped by wide fluctuations in the price of latex.

It is interesting to note that as a result of rising home production of synthetic rubber, which very closely approached 60,000 tons last year, the proportion of the synthetic variety to total new rubber being consumed in this country has risen from around 4% in 1954 to more than 30% in 1959. It is expected that the proportion will continue to increase in favour of synthetic rubber and by 1970 it is probable that synthetic rubber will have gained the major share of the total rubber market; output of something like 190,000 tons p.a. in ten years time is a possibility of which the extended plant at Hythe seems likely to produce the major share.

Since the time it went on stream in 1958 the operation of the plant has proceeded smoothly with the capacity from the polymerisation section apparently in excess of expectations.

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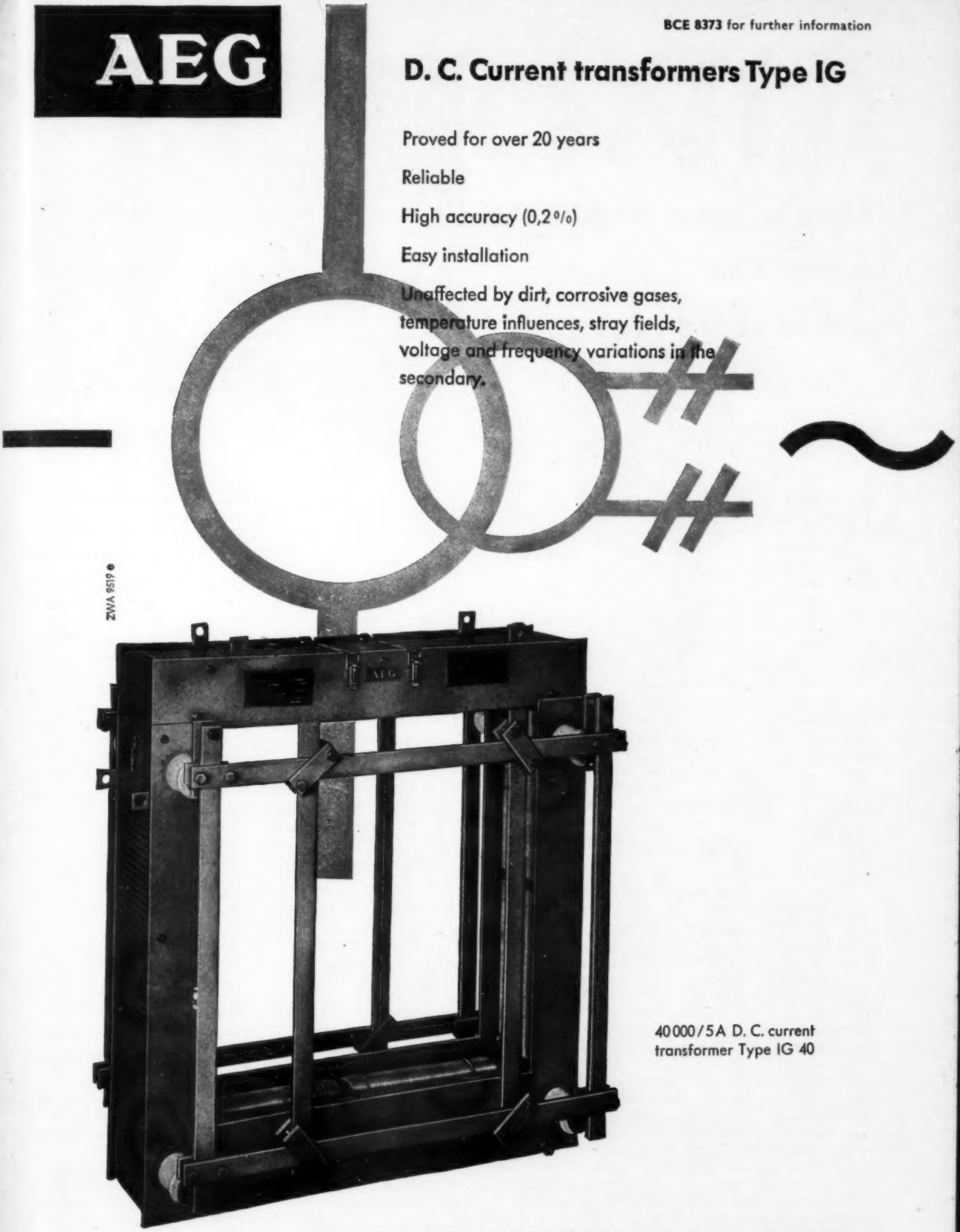

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A 7-cwt valve gate being manipulated in the plating shop at the Kanigen Plant, Oldbury.

CHEMICAL PLATING AND ITS APPLICATIONS

ALTHOUGH the reducing properties of hypophosphate were discovered by Wurtz in 1844, over a century elapsed before their commercial potentialities were recognised by Brenner and Riddell. While working for the U.S. Bureau of Standards upon methods of improving the efficiency of nickel plating processes they obtained results which indicated unexpectedly high efficiencies—in fact greater than 100%. Closer investigation showed that plating could be done without the aid of electricity and, as a consequence, the solutions which made this possible were the subject of patent applications by the Bureau of Standards.

That the General American Transportation Corp. of Chicago were to develop the non-electrical plating process still further was reflected by the series of patents which were assigned to this company in 1953. These covered the solutions and plant for what is now known as the Kanigen* process. The newer process had a number of advantages over those described in the original Brenner and Riddell patents, of which the following are the most important:

(a) A rate of deposition as high as 0.001 in. per hr.
(b) Solution stability improved through circulating it and by regenerating it continuously.
(c) Removal of deposit roughness by continuous filtration. This measure also improved stability, since it helped to remove stray nuclei which are liable to cause spontaneous decomposition.
(d) Homogeneous deposits were now possible through the adoption of continuous recirculation of the solution.
(e) Improved economy.

In the chemical engineering of the process some unusual problems were encountered. For example, the plating temperature is 98°C, but the solution cannot be circulated at this temperature without plating the circuit. This problem was surmounted by cooling the solution immediately it leaves the plating vat. The solution is then pumped to the filtering and regenerating part of the process before it is finally reheated before re-entering the vat. For the "hot" side of the circuit the material used is stainless steel.

Chemically-deposited nickel plate has two main uses:

(a) to prevent corrosion or iron contamination; and
(b) to prevent wear.

In the first field there appears to be no limit to the number of possible applications particularly where neutral or alkaline solutions have to be handled. Where, however, the pH of the solution falls below five, nickel plating cannot be recommended. Among the applications illustrating the first of these two main fields has been the plating of cast-iron valves for the food industry, where the aim was to prevent iron contamination.

At phenol plants interior surfaces of pipework and valves have been treated successfully, again with the object of preventing contamination. Yet another example where prevention of contamination has been the aim is provided by synthetic fibre manufacture, where nickel plating of the spinnerets has overcome the problem of "ironstreaking".

In addition to the contamination-preventing applications, there are numerous uses where the requirement is corrosion protection. These include the treatment of valves at petroleum refineries and at plants handling petroleum products. In some instances it has proved sufficient to plate the gates of gate valves only. Plant which has to withstand the action of uranium hexafluoride also finds a use for this type of plating and in this case attendant advantages are the ability to decontaminate readily and the elimination of iron oxide dust which is extremely dangerous when radioactive.

For storage and transport vessels it is possible for stainless-steel, nickel or nickel-clad steel to be replaced by chemically nickel plated, mild-steel vessels. The nickel is deposited in such cases by making the vessel the plating vat and circulating the solution through it.

Where pipework has to be plated, this is carried out quite simply by pumping the plating liquor through the length of pipe which is attached to a specially prepared jig. For a uniform thickness of deposit it is necessary that the length to bore ratio of the pipe should not exceed 80.

As to the second of the two major fields of application, wear resistance uses are found mainly in the hydraulic field. Here the thickness of the deposited metal is important, as well as its hardness and corrosion resistance. The as-plated hardness is of the order of 500 V.P.N. and heat treatment increases this degree of hardness by another 100 point on the hardness scale. Surfaces with this degree of hardness have excellent wear-resistant properties.

To summarise, chemical-nickel plating may offer corrosion resistance or freedom from metallic contamination sometimes at much less cost than is possible with equipment constructed entirely from corrosion-resistant alloys or metals. The ability to confer freedom from contamination is especially useful nowadays with the increasing demand for more and more purer products.

* Kanigen is the registered trade-mark of the Albright & Wilson Ltd. chemically deposited nickel plating.

BCE 8374 for further information

AMMONIA

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- 8 NEW PLANTS IN THE U.S.A.
- 1,113,000 TONS PER YEAR

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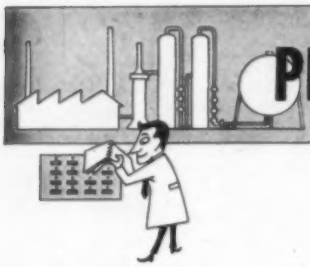
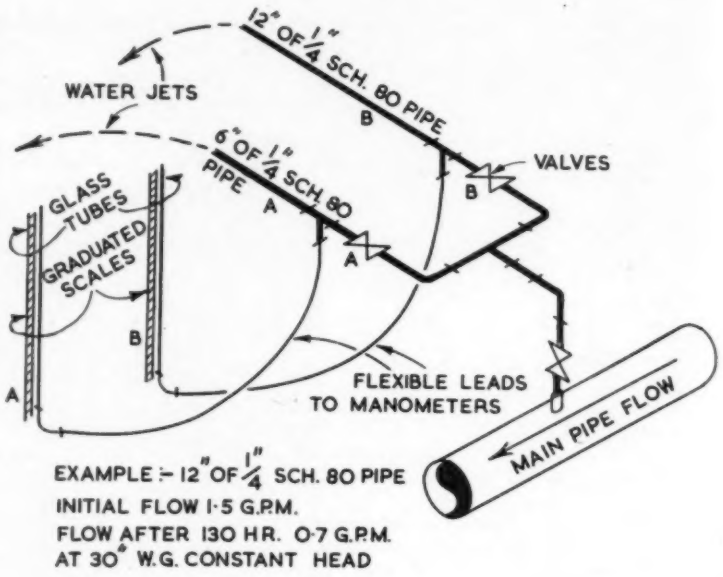


PROCESS ENGINEER'S NOTEBOOK

Testing an inhibitor



THIS SKETCH ILLUSTRATES how field trials were carried out to evaluate an inhibitor in a water-treating system. Requirements were simplicity, since control of the equipment would have to be conducted by plant operators (non-technical staff) over a period of several days. In operation, valves A and B were periodically adjusted to give constant head in open-ended gauge glasses A and B, and the water rate from pipes A and B measured in a measuring cylinder. Quarter-inch pipe was chosen in 6-in. and 12-in. lengths to give an indication of effect of velocity on corrosion.

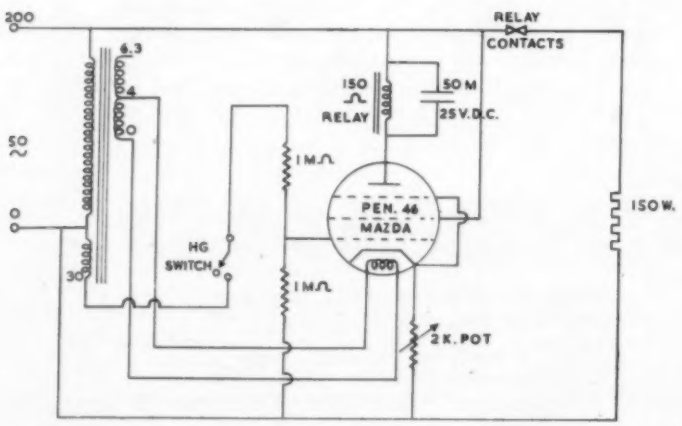
The apparatus proved successful because there was a marked decrease in flow through both ¼-in. pipes over a 100-hour period when no inhibitor was used, but relatively little when injecting the inhibitor into the main line.

The success of the apparatus arose from (1) simple operation; (2) simulation of plant conditions; (3) could be tested over reasonable periods of time.

K.J.J.

Device for measuring small gas pressures accurately

THE DEVICE ILLUSTRATED on page 514 of the July issue of BRITISH CHEMICAL ENGINEERING under this head may well suffer from the disadvantage of being unable to function successfully over long periods of operation.



The mercury contact switch is extensively used, especially in temperature control circuits. Experience has shown however that accurate control over long periods is only possible when a negligible current flows through the mercury switch. Even with a current of a few milliamps, oxidation of the mercury surface is rapid; a clean mercury surface is essential to obtain effective control. The only effective method devised for preventing oxidation of the mercury surface is to put the mercury switch in the control grid circuit of a thermionic valve, using a grid current limiter of 1 megohm or more. This system, of course, necessitates considerable complication of the contact device, as is indicated by the attached diagram; the use of a relay gives aural as well as visual indication of contact. A. JOWETT

Detecting mill scale

THE CONDITION OF the surface of steel plate used for chemical plant, refineries and storage and transport vessels has an important bearing upon the life of such equipment.

As received from the steel makers, the steel plate is covered with mill scale, or magnetic iron oxide, which, in itself, is immune to corrosive attack. However, for two reasons the mill scale is undesirable.

First, it presents a surface which is not a good base for paint, and secondly if it is scraped off, heavy pitting occurs. Should a break appear in the scale, a gouge or score may develop in the metal. In either case, great difficulty results when paint is eventually applied, for the thickness of one coat of even the best paint is only approximately one-thousandth of an inch, and these pits or scratches may be considerably in excess of this.

Removal of the mill scale is therefore an important step in the overall protection of steel, and metallurgists of The Shell International Petroleum Co.—users of vast quantities of steel plate, did a lot of work on the technique of shot-blasting for this purpose. But some method was needed for measuring on the spot the effectiveness of the shot-blasting, for such variables as speed of passing the steel through the blasting process, thickness and hardness of the scale and degree of deterioration of the shot affect the degree of removal. A surface that might appear clean to the eye might still be covered with enough residual scale to reduce the protection offered by paint.

The method devised by Shell's research establishment at Thornton for overcoming this problem requires only the application of a solution of copper sulphate to the freshly blasted steel surface. Areas entirely free of mill scale become coated with copper, while any scale shows up as a dark area against the copper background. The whole operation takes only a few seconds. It needs no more equipment than an impregnated pad or sponge, it can be easily interpreted by the man on the job, and, at small cost, it can help to save some of the £600 million at present lost annually in Great Britain through metallic corrosion.

Increasing the range of a rotameter

ILLUSTRATED IN FIGURE 1 is a simple method of increasing the range of a rotameter by by-passing fluid through parallel-connected "variable resistances" analogous to switching in multi-range electrical meters.

With the arrangement shown, the rotameter may be used alone (stopcock off), with either resistance separately, or with both resistances in parallel (stopcock fully open), giving a total of four ranges.

The first valve should be adjusted to continue the range from near the top of the rotameter's natural range. A small measure of overlap is advisable. Similarly, the second valve should continue the third range from near the end of the second. Finally, calibration curves should be constructed giving rotameter reading against flow rate. Some typical curves taken in this Department are shown in Fig. 2. Direct reading scales may be constructed from the calibration curves. As an idea for manufacturing purposes, the four scales could be on a rotatable turret coupled to the tap.

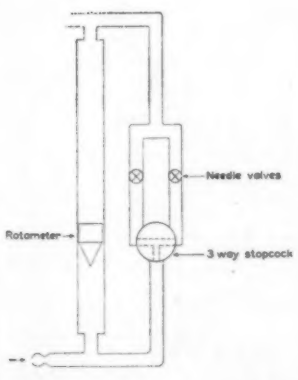


Fig. 1

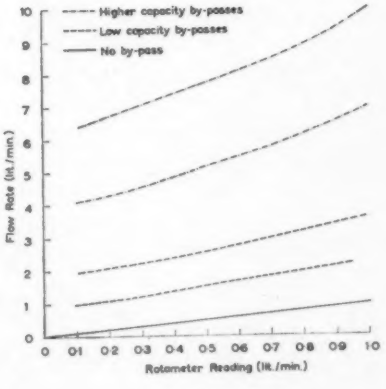


Fig. 2

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

PHYSICAL PROPERTIES OF CARBON MONOXIDE AT ATMOSPHERIC PRESSURE

by A. M. P. TANS*

The accompanying nomogram gives the physical properties of carbon monoxide at atmospheric pressure. It has been constructed from literature values.[1]

The use of the nomogram is as follows: Any straight line passing through the centre intersects the scales in corresponding points.

* Central Laboratory, Staatsmijnen in Limburg, Geleen, Netherlands.

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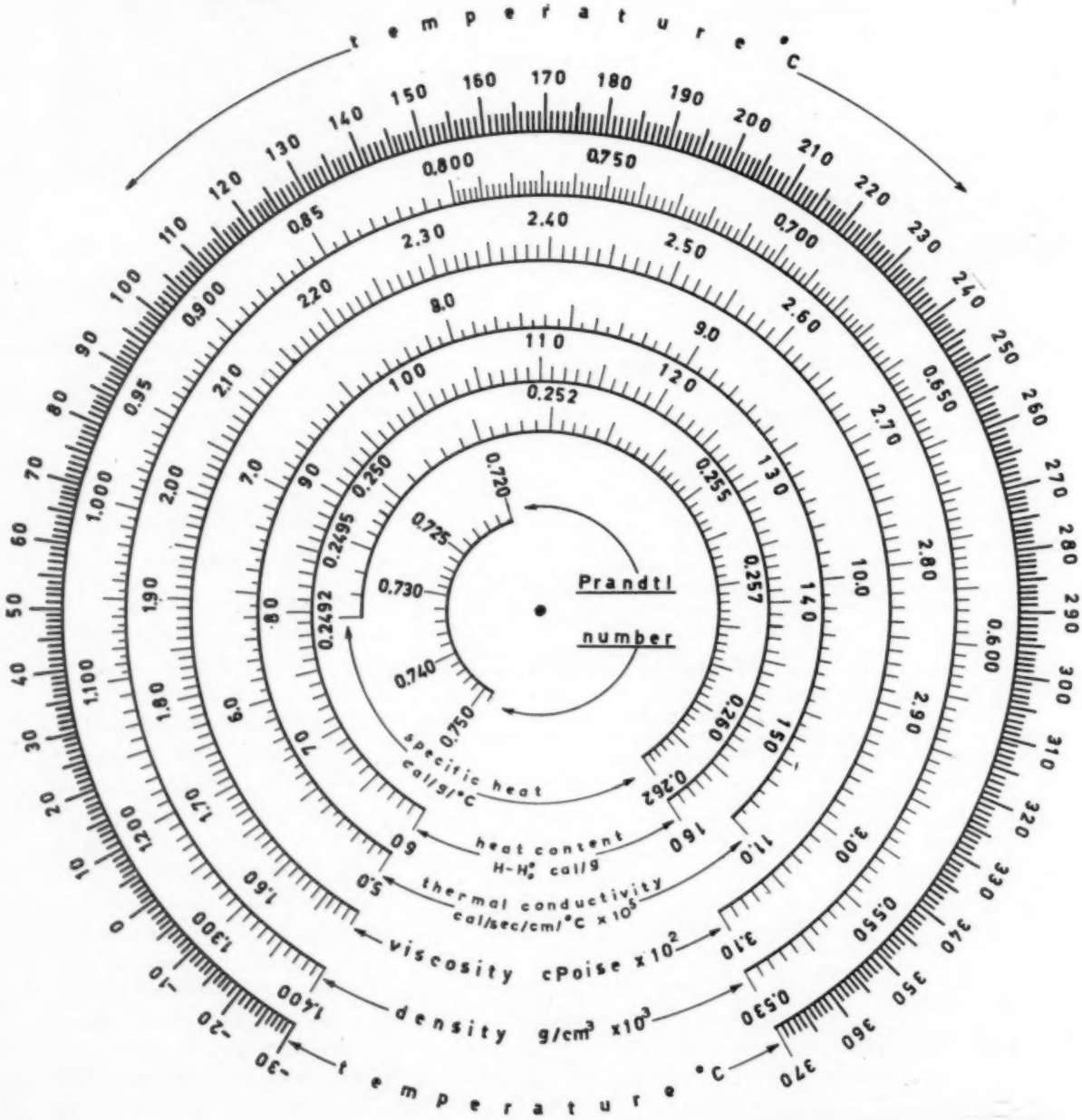
[1] Hilsenrath, J. e.a. "Tables of Thermal Properties of Gases", National Bureau of Standards, Circular 564, 1955.



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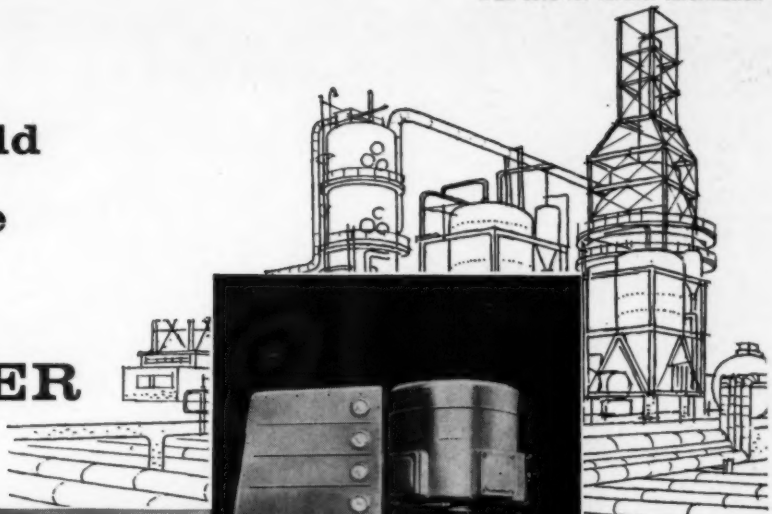
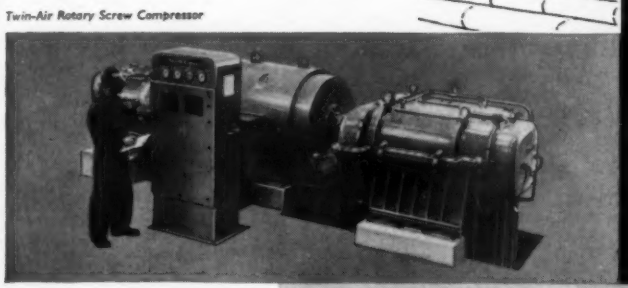
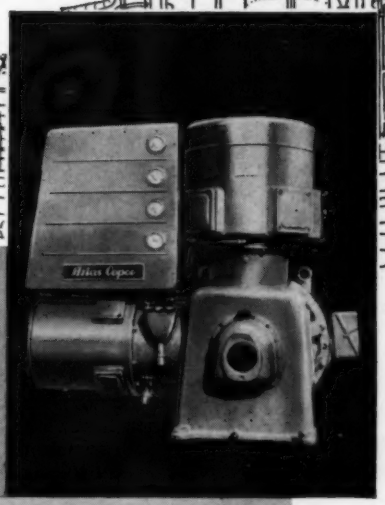
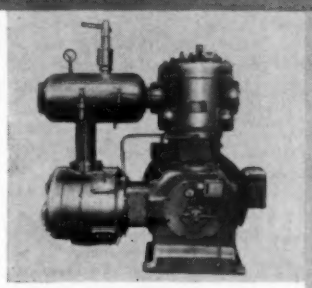




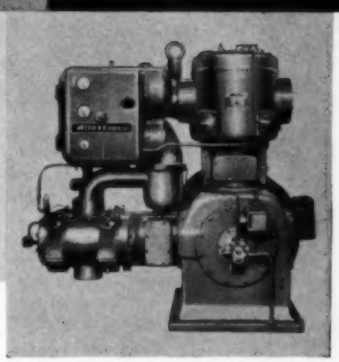
Twin-Air Rotary Screw Compressor



ER6 Compressor



AA-type low pressure Compressor



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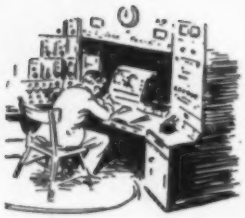
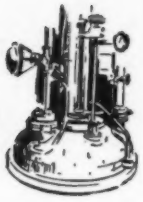


LETTERS TO THE EDITOR



Surface Treatment of Storage Tanks

Dear Sir:

I was surprised to see in the article entitled "Surface Treatment of Storage Tanks" appearing in your August issue that pickling of steel by the sulphuric/phosphoric acid process can only be carried out in plant installed at or near steel mills, as such is not the case. My company has been operating the process for over 25 years and there are plants operating in other contractors' works in various parts of the country whose location is in no way dependent on steel mills. I should be pleased if you would kindly bring this fact to the notice of your readers.

As the authors were not aware that the process may be carried out in contractors' works, it might be worth while mentioning a major advantage of this procedure. The contractor makes pickling and painting the last operation to which plates, etc., are subjected before they are dispatched to site and, by so doing, damage to paint is negligible. If the contractor received material for fabrication which had already been painted after pickling, damage during rolling and welding preparation operations cannot be avoided and a lot of touching up at site after erection would be necessary. I wonder, in fact, if this is not borne out by the authors' description of the priming paint at sites A, C and D. Mention is made of considerable damage to paint during erection at sites A and C, but very little at site D. It would be interesting to know if at site D the pickling and painting had been done at the contractors' works and that for material for sites A and C elsewhere, because I suspect that the heavy damage reported occurred before receipt of material at site and not during erection.

With regard to the economic considerations reported, I trust these will not be regarded as applying generally to pickling and the associated painting of structural steelwork, because usually it can be justified economically. An important factor is the repainting interval and this is certainly longer for pickled steel than for weathered surfaces—it may be as long as ten years, depending on atmospheric conditions. The initial cost of the process is of obvious importance and regarding this I would say that the present-day cost of pickling by the sulphuric/phosphoric acid process at contractors' works and immediate prime painting is several hundred pounds lower than the cost quoted in the article for the 96 ft dia. × 54 ft high tank.

One last point; no mention is made of the greater loss by evaporation of petrol and other volatile liquids when stored in tanks left to weather. The loss from such unpainted tanks may be expected to be considerably greater than from painted tanks.

Yours faithfully,

C. H. CHALLIS,
M.I.Chem.E., Assoc.Inst.GasE.
Whessoe Ltd.,
Darlington.

Flow through Tower Packings

Dear Sir:

With reference to the article "Gas and Liquor Flow Through Random-packed Raschig Rings" (BRIT. CHEM. ENG., March, 1960, p. 179), the following statement is in error:

> "It is worth noting that when the walls of Raschig rings are perforated (Pall ring) the pressure drop for a given gas flow, measured on an empty column basis, is decreased. This suggests that the ... inner spaces receive a greater proportion of the gas flow than with normal (Raschig) rings. Performance data concerning Pall rings are given by Pfannmuller (*J Inst. Chem. Eng.*, 1954, pp. 121-4), who states that dry Pall rings 50 mm (outside) diameter produce only 0.69 of the pressure drop associated with Raschig rings of 50 mm (outside) diameter under the same circumstances."

The pressure drop for beds of Pall rings, in fact, is greater than for Raschig rings by a factor of 3/2.

The original data, already cited, is misleading, because metal (i.e., thin wall) Pall rings were compared with ceramic (i.e., thick wall) Raschig rings. This fact was not mentioned in the article by Pfannmuller.

With reference to tower mechanics literature in general, the data for packings in the form of charts show a number of inconsistencies and should therefore be used with caution.

Yours faithfully,

A. J. H. BROWN,
46 Merryton Avenue,
Giffrock,
Glasgow.

Author's Comment

Mr Whitt has commented as follows upon Mr. Brown's letter: The data given by Pfannmuller were taken in good faith from his article as given in the reference, which quotes the factor and shows it on a plot. The literature, accessible to the general public, nowhere states that it is in error, so it was assumed that like rings were compared.

I was interested in Mr. Brown's statement that the pressure drop for Pall rings is greater than for Raschig rings. Were his rings 50 mm size as were those quoted in the Pfannmuller article*? Rings of other sizes may show different behaviour and give different comparisons as far as pressure drop results are concerned.

I agree that the data for packings in the form of charts can be misleading. The data used in the article, however, were plotted in similar forms for both hollow and solid rings, i.e., gas flows corrected for temperature is one point in particular not always taken notice of in the early days. The plots were the average of different dumpings for both types of rings, another factor often overlooked. These points are brought out in the original paper quoted — Hands, Whitt and Gregory—on whose results the paper in BRITISH CHEMICAL ENGINEERING is based. I was personally concerned with this work in the greatest detail. The aim of the former work by Hands, Whitt and Gregory was to obtain data useful for calculating the pressure drop in distillation columns (as distinct from absorption columns). The flows of gas through distillation columns are higher and the liquid rates lower than is general in absorption columns. Hence air rates up to several fps were used, an area of work not explored prior to the date of the paper. Relatively low liquid rates were used, and care was taken to obtain a number of results before attempting to make generalisations, i.e., different dumpings, as previously mentioned.

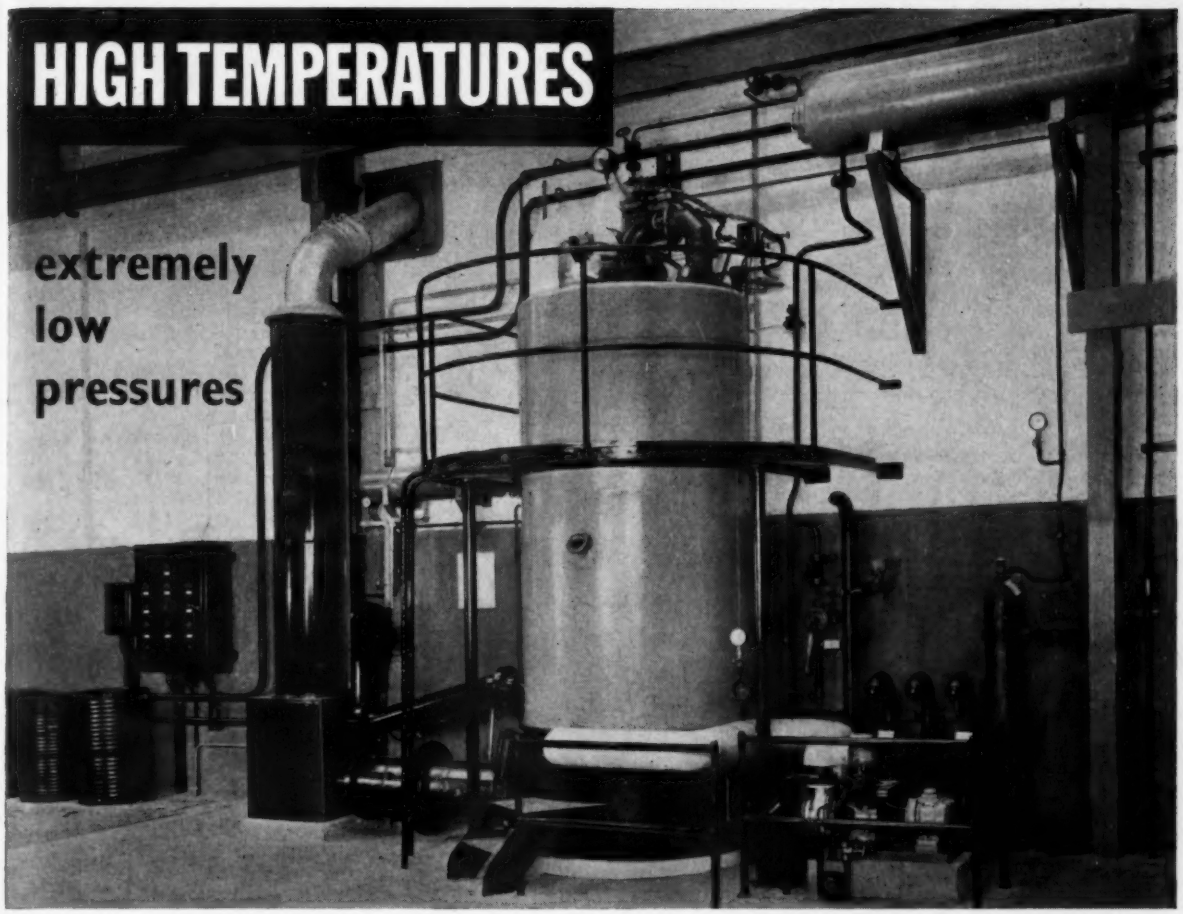
It can thus be said that the comparisons for hollow and filled Raschig rings were based on data obtained from work under comparable circumstances.

Comments Welcomed

Letters to the Editor

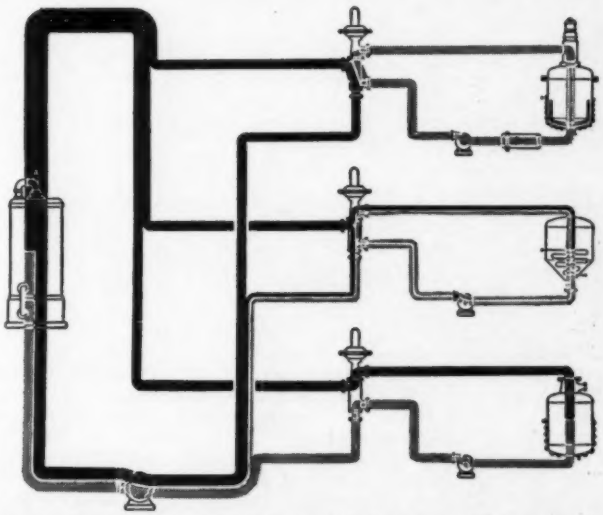
Readers' letters, provided they deal with matters of relevance to chemical engineers, are welcome for publication. While it is to be expected that most letters will be concerned with articles or viewpoints that have appeared in the columns of this Journal, this will not exclude the publication of letters which ventilate matters of interest to the profession but which have not previously received mention in this Journal.

* Mr. Brown has indicated that his rings were, indeed, 50-mm rings.



With automatic control of several vessels at varying temperatures up to 700° F. from one boiler with liquid medium

Flow diagram illustrates use of unique 4-way valve to give cooling : intermediate or maximum temperatures



Bertrams ROSEDOWNS System

High Temperature Heating Plants

ROSE, DOWNS AND THOMPSON LIMITED

OLD FOUNDRY, HULL, ENGLAND. Tel. 29864. London Office:—15, Portland Place, London, W.1
DAVY-ASHMORE GROUP Tel. LANgham 5588

Book Reviews

Plastics Engineering Handbook—Third Edition

Reinhold Publishing Corporation, New York, Chapman & Hall, London, 120s.

THIS handbook has been compiled by the American Society of the Plastics Industry and contains a wealth of information. In addition to definitions of terms and the classification of rigid moulding materials with their properties, comprehensive chapters on the various forms of moulding processes, preforming and drying, extrusion are included. Methods of fabrication, the design of moulded articles and the standards for tolerances, mould and die design make this an almost essential book for the designer who will find further valuable information from chapters on cementing, welding and assembly of plastics. Comprehensive charts, diagrams and illustrations make this one of the most valuable handbooks to be published.

R.C.

Structure and Properties of Thin Films

Edited by C. A. Neugebauer, J. B. Newkirk and D. A. Vermilyea

John Wiley & Sons Inc., New York, and Chapman & Hall, London, 1960. 561 pp., 120s.

THIS publication, which is a full report of the contributions and discussions at what appears to have been the most important meeting hitherto held on the subject of thin films, is remarkable in that it has been produced in about a quarter of the time usually taken for the issue of such reports.

The undoubted success of the meeting, which was sponsored by research organisations of the U.S. Air Force and the General Electric Co., and was held at Bolton Landing on Lake George, New York, in September 1959, is probably due to selection of the 66 participants by a committee consisting of one member each from Harvard University, the U.S. Bureau of Standards, Cambridge University, Imperial College and the G.E.C. Research Laboratories.

The films dealt with are practically all metallic and produced by condensation *in vacuo*, or by rolling followed by electro-polishing or chemical treatment.

The extent to which a condensed film is susceptible to contamination by adsorption of residual gases is given due consideration, and care is taken throughout the proceedings to distinguish between those properties of the films which are likely to be possessed by the bulk material and those which are not.

Of special interest in the report are a discussion on the theory of surfaces, and five reviews, covering processes at gas-solid interfaces and the formation, microstructure, electrical conductivity and mechanical and magnetic properties of thin metallic films.

Somewhat surprising, however, in view of the title of the report, is the absence of any contribution on oxide films, or films produced by electro-deposition, or on the use which has been made in England, particularly at Cambridge, of the study of thin films of aluminium alloys in the investigation of age-hardening of those materials.

The report is well produced and the excellent illustrations, many of which have already been published or shown at preveious meetings, include some fine new field emission micrographs by E. W. Müller, showing vacancies, interstitials, α-radiation damage and the effect of corrosion.

The editors' hope, expressed in their preface, that the information contained in the papers and discussions will be useful to all concerned with thin films, seems likely to be realised; new-comers to this field will find particularly useful the reviews and the very complete references appended to the contributions.

H. I. MATTHEWS

Status Report on Fuel Cells by B. R. Stein, ARO report No. 1, June 1959, Office of the Chief of Research and Development, Department of the Army Washington, 25, D.C.

In November, 1958, under the sponsorship of the Department of Defence, a Seminar on Advanced Energy Sources and Conversion Techniques was held at Pasadena, California. As a result of this meeting it was agreed to publish a report on the status of fuel cell activities. This report is therefore the first of a series intended to collect and review all available information in this field. An attempt has been made to note the more important basic facts and develop a comprehensive bibliography for reference purposes. All fuel cell activities pursued or contemplated by the U.S. Army are mentioned. An attempt has been made to secure the same information from other agencies, though no indication can be given that complete success was achieved. In subsequent reports it is planned to remedy this situation.

High Temperature Materials

by R. F. Hehemann and G. Mervyn Ault

John Wiley & Sons, Inc., New York, and Chapman & Hall, London, 1959. 544 pp., 140s.

EVERYBODY knows that we have just entered the Space Age, but few people realise that the keys that have opened the way to it are the materials this book is concerned with. Whatever the power plant will be that takes the first man to Venus, it will be built from materials descended from those dealt with in this book.

There was a time when those in the van of technical developments not only had the leisure to write books, but, more important, had the time to acquire profound knowledge in a broad field. Today no specialist in high-temperature materials could be expected to write an authoritative book on the subject single-handed. This is true of many other fields too; hence the increasing tendency, particularly in the U.S.A., to get books written by organising a symposium or a conference. This volume is the result of such a conference held in Cleveland in 1957 and sponsored by the High Temperature Alloys Committee, Institute of Metals Division, The Metallurgical Society, American Institute of Mining, Metallurgical and Petroleum Engineers.

There are 32 papers by 52 authors, all American and all well-known specialists in their respective fields. Each paper quotes numerous references, many of them European; nevertheless, the absence of even a single European contributor could easily mean that in this vital technological field we in Europe are well behind in the race.

The papers cover cobalt and nickel-base alloys, cermets and intermetallics, and refractory materials. Five papers are devoted to vacuum melting and its effects on properties, four deal with the effect of testing environment on properties, and three with oxidation resistance, and it is to be assumed that as much up-to-date information is contained in these papers as the various companies to whom the authors belong decree prudent to release at the present.

As with all such collections of papers, the book suffers from the defect that there are gaps—there is not a single reference to welding, for instance, in the index—and there is inevitably a certain amount of repetition and overlapping. This fact, of course, has its good points because careful study will bring out differences in opinion, and since the book only contains the papers of the conference and unfortunately not the discussion this must be considered an advantage.

There is undoubtedly a wealth of information, and no one concerned with production, fabrication or application of high-temperature materials can ignore the book.

R. WECK

Use of Flammable Liquids in Factories. Ministry of Labour Form 1447.

THIS ADVISORY LEAFLET was due to have been sent to every factory owner or occupier by Mr. T. W. McCullough, the Chief Inspector of Factories. It draws attention to the need for knowledge of the properties of the liquids used, and what the associated risks are. Measures described include restriction of the spread of any spillage of flammable liquids, the removal of vapours by ventilation, cleaning empty vessels, the safe distribution of liquids, and the elimination as far as possible of all sources of ignition from rooms, or other enclosed spaces where there are flammable liquids.

B.S. 1389:1960. Dimensions of Hose Connections for Welding and Cutting Equipment, 4s.

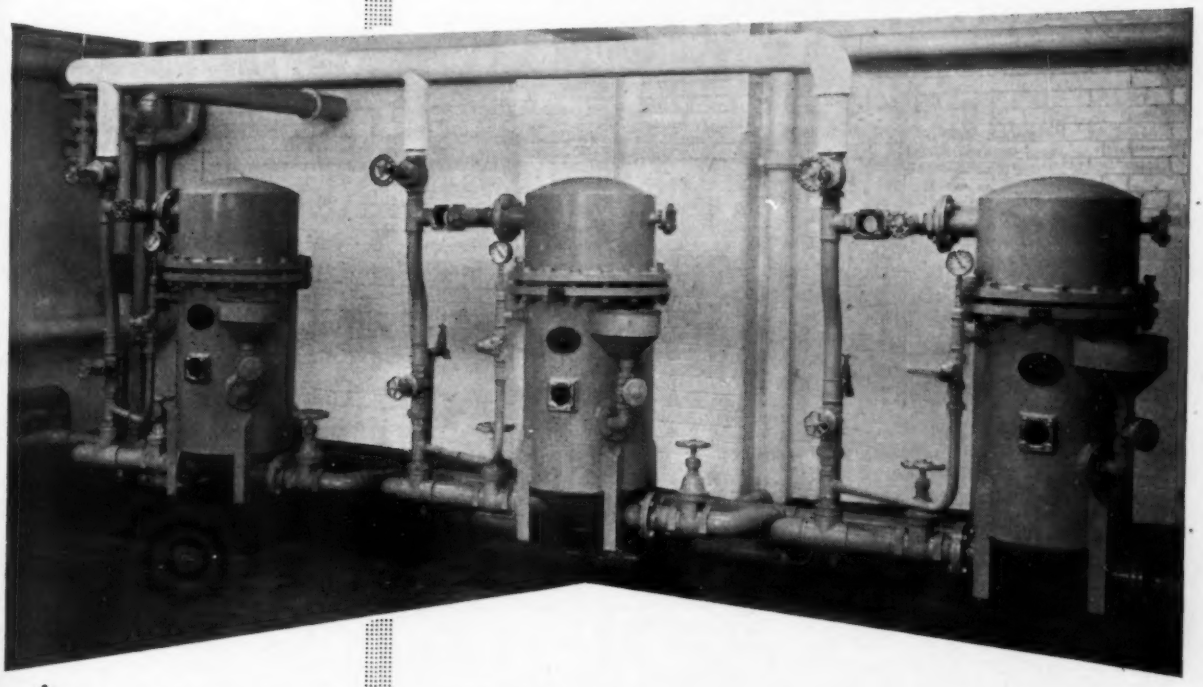
IN THE PRESENT revision of this Standard the range of sizes of hose connections used in gas welding and cutting has been extended to include five sizes. The size of connection to be used for a given application is not specified, but it is recommended that the size of connection at the supply end of a hose assembly be not less than the size at the discharge end. Metric equivalents of the dimensions have not been included.

BCE 8377 for further information

Safeguard your liquid assets*

Liquid assets in the shape of edible juices and industrial fluids, chemical solutions, oils and spirits are too valuable to be wasted. They need the Stellar Filter to safeguard them, to render liquid loss almost negligible whilst clarifying and purifying. Designed to operate with supreme efficiency, the Stellar Filter has an unchokeable filter bed and is perfectly simple to control. It is remarkably economical, too, for it can be cleaned without dismantling or loss of liquid, and occupies very little ground area.

Tell us your problem and we'll gladly advise you how and why the Stellar Filter will take good care of your liquid assets.



* *They may be WAXES—OILS ESSENCES—WINES—SPIRITS JUICES—CHEMICALS PHARMACEUTICALS SYNTHETIC RESIN SOLUTIONS SOLVENTS—VARNISHES INDUSTRIAL FLUIDS—and, of course, WATER*

with the

STELLAR FILTER

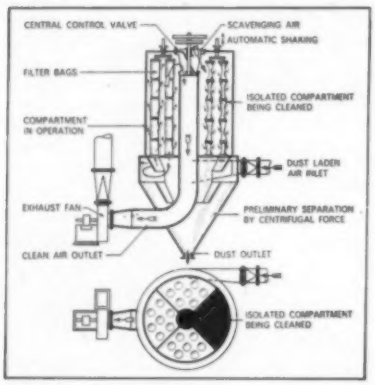
...another Paterson *design for purity*

THE PATERSON ENGINEERING CO. LTD., 129 KINGSWAY, LONDON, W.C.2

PLANT EQUIPMENT NEWS

Holmes Standard Bag Filter

This bag filter will handle heavy dust burdens and is guaranteed a collection efficiency in excess of 99% of all particles, including those in the sub-micron range. The heavier particles are separated by cyclonic action, and the finer dust particles which rise in the air stream are collected in the fabric of the filter bags. One of the four or six compartments is always isolated for cleaning purposes.



This is done automatically with a valve mechanism and geared motor unit. Different sizes are available with effective filter areas ranging from 67.3 sq. ft. to 2,238.1 sq. ft and corresponding capacities ranging from 565 cfm to 18,365 cfm. **W. C. Holmes & Co. Ltd., Gas Cleaning Division, Turnbridge, Huddersfield.**

BCE 8433 for further information

Self-cleaning Filter

The Tornado-Fischer automatic self-cleaning filter, which is new to this country, is described in the firm's Publication No. 51. The filter elements and fabric are specially designed to handle dust particles of virtually all sizes. There is a patented cleaning mechanism, and maintenance requirements are negligible. All moving parts except the motor are in dust-tight enclosures. The filter will handle a wide range of dusts, including blast furnace slag, carborundum, cement, coal, fertiliser, fluor-spar, lime products, slag-sand and stone dusts. The temperature of the air or gas passing through can be as high as 350° C. **Keith Blackman Ltd., Mill Mead Road, London, N.17.**

BCE 8434 for further information

Electric Actuators

Redesign of an established series of electric actuators for valves has led to considerable reduction in size. The actuators are suitable for powered automatic remote and local control of a wide range of types of valves—with the rising or non-rising spindle. They can be supplied for fitting to an existing valve or complete with a valve. Standard construction is flameproof and flameproof-weatherproof construction is also available. The actuator is designed to include protection against valve overtravel and motor overload. There is a controlled centrifugal transfer clutch which provides instant availability of hand or power operation; ensures full safety interlock between hand and power operation and automatically transfers to power operation immediately circuits are completed for motor operation. The handwheel is disengaged without shock or impulse being felt by any person attempting manual operation. The clutch allows the motor to start up and attain speed before taking up the load, provides full mechanical protection during transfer period to stationary gearing and finally permits instantaneous reversal of the motor under no-load conditions. **Jones, Tate & Co. Ltd., East Parade, Bradford.**

BCE 8435 for further information

Small Industrial Meters with Connector Sockets

To simplify the installation of small case industrial meters, where meter connectors are used, a flanged tapered socket incorporating a female B.S.P. parallel thread has been developed for the North Thames Gas Board. This fitting is known as a "Connector Socket" and is bolted to the side of the meter in place of the conventional Donkin or B.S. flange. These sockets are now available to other Boards and can be fitted on request by all makers of industrial meters.

While the overall width of the meter remains unchanged and so permits interchangeability between meters fitted with flanges or sockets, the use of this new fitting eliminates the necessity for companion flanges, washers, nuts and bolts. Meter connectors are forms of long-screws. The connector sockets have been so designed that, although the overall width of the meter remains unchanged, the parallel thread portion of the connector may be screwed into the socket without fouling the sides or interior gaswaus of the meter.

The socket for the outlet of the meter is provided with a plug which may be removed for the purpose of purging the meter on installation. Recommended design dimensions of connector sockets and sizes for meters from 1200 ft/h to 15,000 ft/h capacity have been specified. **Report No. 716/59 of the Industrial Gas Development Committee of the Gas Council.**

BCE 8436 for further information

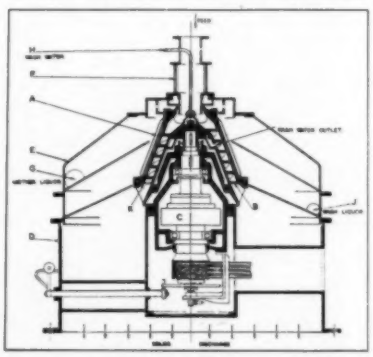
New Screen-type Centrifuge

The separation from liquids of fibrous and granular solids as well as free draining powders can be accomplished economically in a new continuous screen-type centrifuge.

This machine, known as the Dynoscreen, a product of International Combustion, consists in essence of a rotating perforated cone (A) carrying a screen. A screw conveyor of similar conical section (B) rotates within the perforated cone at a speed slightly in excess of that of the outer cone. The speed difference is obtained by means of a special gear unit (C) incorporated in the main shaft.

The solids are deposited on the inner surface of the screen, while the liquor passes through the bed of solids to be discharged through the outlet connection (G). Wash liquor is introduced at point (H) and is fed into the bed of solids at a distance along the helix and is discharged through connection (J). Solids are discharged from the annular gap between helix and screen through the rubber-lined base of the centrifuge casing.

Horsepowers for the four different sizes of machine are in the range of 10-30, and the larger diameters of the conical basket are 10, 12, 16 and 20 in. respectively.



Speeds of rotation provide separation factors up to 2000 × g and capacities, depending upon solid and liquid properties, vary from 0.5 to 8 tph.

For effective separation it is not essential for the specific gravity of the solids to be greater than that of the liquids in which they are suspended. The rotating members are readily accessible so that cleaning and screen charging are easy to perform; the feed is via a sight glass, and lubricant is pump circulated to the bearings. **International Combustion Products Ltd., 19 Woburn Place, London, W.1.**

BCE 8437 for further information

New P.V.C. Sheet

A tough thermoplastic sheet of excellent chemical resistance and high impact strength has recently been developed by

New Sharples Super-D-Hydrators

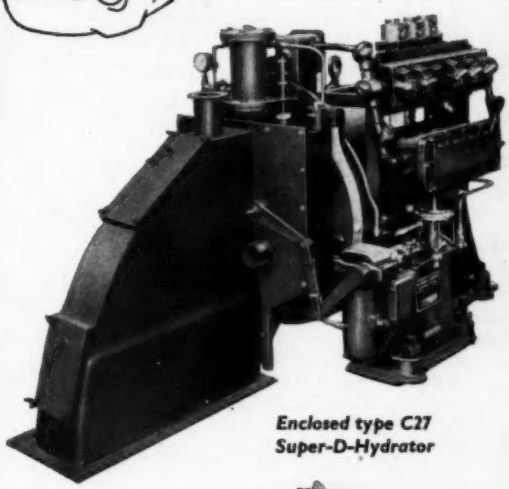
in the world's most complete range of centrifuges

Even before the latest additions, Sharples was the most complete range of centrifuges in the world. Now it's better than ever, with brand new models of Super-D-Hydrator.

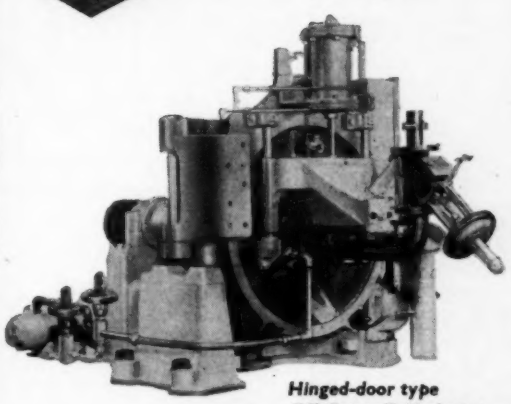
What do the new models mean ? The unique design features of the Super-D-Hydrator are of course retained. High centrifugal force, and completely automatic and continuous operation, continue to supply a solid foundation for the new designs. To these basic characteristics are now added increased capacities and ready availability for inspection, together with the refinements of totally enclosed operation for toxic hazardous materials. Antibiotics can be handled most successfully in a sterile version of the D-Hydrator, while special arrangements can be made for operation at either very high, or very low temperatures. Add up all these designs, and there's a properly tailored answer for every problem of crystal dehydration.

To Sharples world wide experience of some 2500 D-Hydrator installations is now added greater flexibility of operation through the application of careful detailed design, which is the hall-mark, " Sharples."

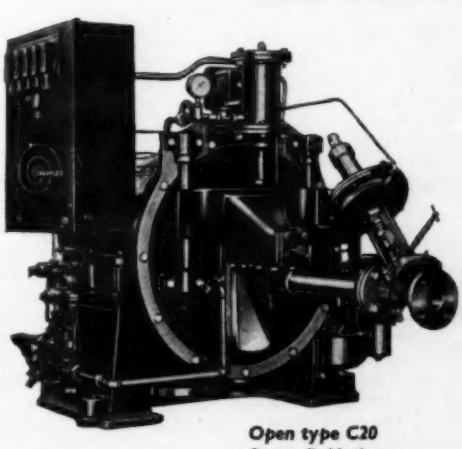
If your problem is the separating, washing and dehydration of any sort of crystal, and you desire consistency of product, combined with automatic and continuous operation, then you are invited to write to the address below or 'phone Camberley 2601 and talk it over with Graham Jackson.



Enclosed type C27 Super-D-Hydrator



Hinged-door type C41 Super-D-Hydrator



Open type C20 Super-D-Hydrator

SHARPLES

SHARPLES CENTRIFUGES LIMITED
TOWER WORKS, DOMAN ROAD, CAMBERLEY, SURREY
Phone: Camberley 2601 *Grams: Supersplit, Camberley*

PLANT EQUIPMENT NEWS

Bakelite Ltd. It is a new grade of P.V.C. known as VYBAK DVR.258. This material is a rigid/flexible composite sheet and particularly suitable for tank lining applications. The flexible portion gives added strength to the sheet and is more easily cemented to metal than rigid sheet. The rigid side has a better chemical resistance than the flexible side.

DVR.258 may be sawn, drilled in woodworking or light engineering machines, and is easily welded by hot gas welding technique. **Bakelite Ltd., 12-18 Grosvenor Gardens, London, S.W.1.**

BCE 8438 for further information

Ceramic-lined Centrifugal Chemical Pumps

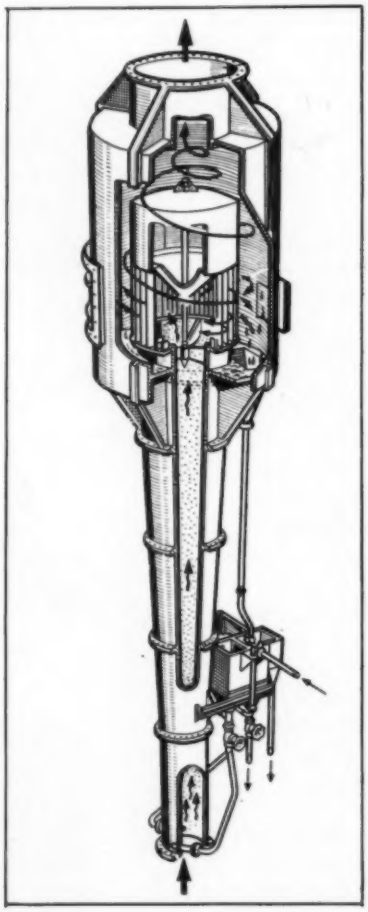
A range of ceramic-lined centrifugal chemical pumps of recent design takes advantage of the extreme acid resistance of ceramic materials whilst embodying modern conceptions of pump design. The aim has been to employ the ceramic as a lining rather than as a load-bearing material and this has resulted in a construction which virtually eliminates the possibility of damage from mechanical shock and gives great rigidity with excellent impeller alignment. The ceramic linings are bonded to cast-iron casings. The open-type impellers are produced in either tough, shock resisting ceramic, in acid-resisting metal alloys or in titanium. A range of stuffing-box and mechanical seal arrangements can be fitted. Grease lubricated ball and roler bearings are used throughout and are amply rated for long service in continuous operation. The design allows easy maintenance, there is no need to disturb suction and delivery piping when inspecting or servicing the pump, nor yet is any lifting tackle necessary, as the complete bearing bracket, impeller and rear cover can be slid out as one unit. Interchangeability of spares is guaranteed and hydraulic performance can be accurately reproduced. The hydraulic design gives maximum efficiency over a wide capacity range with a stable head/capacity characteristic and low suction velocities. The present range covers duties up to 120 ft head and capacities up to 400 gpm and temperatures to 100°C can be accommodated. **Craig Pumps Ltd., Burnfield Road, Giffnock, Glasgow.**

BCE 8439 for further information

New Wet Collector

The Airmix wet collector which has just been developed has a variety of uses in applications involving industrial dust collection. Apart from its use on new systems, it is easily adapted for installation as a secondary collector on existing plants where increased efficiency is desired.

This device is a self-induced spray-type vertical venturi wet washer which separates the dirty water from the cleaned gases by means of centrifugal action. The washing water is fed tangentially to the venturi throat by two, three or four pipes, depending on the size of the collector. The gases flowing through the throat at high speed spread the water on to the cylindrical surface in a continuous film and at the same time carry it vertically. The great difference in the velocity of the two fluids causes the gas to break up the waves which form on the surface of the water film, thus intimately mixing the dust-laden gas and the water droplets in the fine spray produced.



The mixture then enters a tapered diffuser section where its speed is slowed down and the dust particles which have so far escaped are wetted as the dust-laden gas again passes through a cloud of water droplets which, owing to their tendency to agglomerate, have a slower upward movement. Upon reaching the top section of the Airmix, the mixture is diverted into a ring of curved vanes which impart a strong rotational motion which separates the gases and water by centrifugal action. Any particles still in a dry state are wetted by impingement with the vanes. The dirty water is evacuated by a discharge pipe and the cleaned gases pass out through a chimney.

There are two types of sludge disposal system available, one consisting of a small three-compartment tank which separates the slurry through a discharge valve and another consisting of a large two-compartment sludge settling and dewatering tank in which the sludge is allowed to settle for eventual discharge down a chute into lorries for disposal, the clean water being fed in both cases back to the venturi throat.

The Airmix has been successfully used on coal, coke, sugar, in the foundry and quarrying industries and in many other fields. It has been used in the chemical industry for the drying of chlorine, for the washing of nitrous, sulphurous and ammoniac vapours and as a pre-filter before a wet electrostatic filter.

The unit is constructed of mild steel and is available in a range of standard sizes with capacities from 1300 cfm to 30,000 cfm. For handling larger volumes a number of smaller units can be operated in parallel. A galvanised finish or, for certain applications, corrosion-resistant linings or special materials such as stainless steel can be supplied. **Thermix Industries Ltd., 143 Maple Road, Surbiton, Surrey.**

BCE 8440 for further information

Modular Instrument Design

A major step forward in instrument design is claimed by Honeywell Controls with their new modular ElectroniK design which embodies four self-contained and easily removable sub-assemblies as features of the company's indicators, recorders and controllers. The chief benefits are said to be easier servicing, lower maintenance costs and high accuracy. A special feature is the constant voltage unit, said to eliminate periodic standardising and battery replacement. **Honeywell Controls Ltd., Ruislip Road East, Greenford, Middlesex.**

BCE 8441 for further information

Paint Based on Synthetic Rubber

A new, versatile, liquid coating having elastomeric properties has been developed under the name "Texseal" by the Chemical Products Division of the Dunlop Rubber Co.

It is based on Hypalon synthetic rubber, a chlorosulphonated polyethylene. Its properties include chemical and ozone resistance and therefore it will be found useful for protection against corrosion in chemical plant and structural steelwork. It has a good flame resistance and may be used continuously at temperatures up to 250°C.

"Texseal" may be applied to a variety of materials such as concrete, steel, fibreboard, wood and rubber with good adhesion between the coating and base material. It may be applied by brush or spray. **Vicsteels Ltd., 16 Northumberland Avenue, London, W.C.2.**

BCE 8442 for further information

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Important anti-fouling effect,
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PLANT EQUIPMENT NEWS

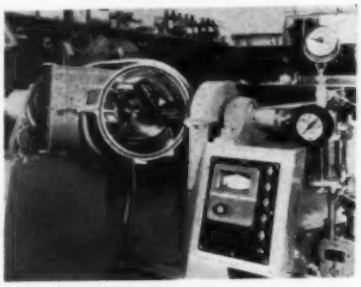
Surface Heaters

A wide range of industrial electric surface heaters is made by Isopad Ltd., who recently invited us to visit their factory and inspect their production and design facilities. These heaters are now being applied to a variety of process vessels, pipelines, valves, instruments and drums. In a typical Isomantle the heating surface consists of strong special weave glass cloth withstanding temperatures of up to 550°C, thus allowing the use of liquid temperatures of up to 350°C; it is resistant to most chemicals. The heating elements, electrically insulated by glass fibre or glass/asbestos rovings, are fitted to the glass cloth. Low resistance connections lead from the back of the heating surface to the external junction box. Insulation material of 2-4 in. thickness provides thermal lagging, while a strong stove-enamelled metal enclosure protects the assembly and ensures attractive appearance. Heating surface is often subdivided into several zones which can be independently controlled. The thermal mass of the heating surface is small, allowing the heater to respond speedily to an adjustment of controls. This property also eliminates thermal stresses and shocks, making the system especially suitable for use with enamelled and glass-lined metal vessels. Cut-outs for bottom and side outlets, heating and cooling coils, thermometer pockets and so on are provided as needed. The illustration shows a LaBour pump heated in this way. Flameproof construction is also available. In this the heating element fitted to the glass cloth heating surface is mineral insulated and metal sheathed (usually in stainless steel), terminating in a flameproof gland and flameproof junction box. The assembly itself is flameproof but the surface temperature of the heating element must be kept below the ignition temperature of the vapours or gases present. These units carry a three-year guarantee. For high power/high temperature work, special quartz cloth—made of 98% SiO_2—is used instead of the standard high-temperature glass cloth. The quartz cloth withstands element temperatures up to 800°C, allowing for 600°C or more in the liquid. Finally, where fast heating-up rates are required and powers in excess of the standard loading of the normal resistance units must be applied, a mains frequency induction heating system is recommended which caters for a heat input of 4000-5000 Btu per sq. ft (13,500 kcal per m^2). Induction currents flow in the shell of the vessel providing the main heat input, whilst the base of the vessel is usually heated by a robust Isomantle. Equipment is supplied complete including all necessary instruments and controls. Brochures are available. **Isopad Ltd., Barnet By-Pass, Boreham Wood, Herts.**

BCE 8443 for further information

Combined Blender and Drier

The precision blending and drying of a variety of chemical formulations with the minimum handling of materials is made possible by the introduction of a new packaged unit developed by Patterson-Kelley. The new combination makes use of the company's twin-shell mixer and, in addition, a hollow cylindrical dispersion bar is mounted across the blender axis. Through this bar fluids can be added to the solid charge in the mixer. To the original twin-shell mixer has been added a heating jacket, a vapour discharge connection and other drying components, including filters, condensers, receivers, vacuum pump and instrumentation.



A wide variety of processing environments is provided by the new design; thus, gentle tumble blending can be carried out under either atmospheric or vacuum conditions or in the presence of an inert or sterilising gas and temperatures in the jacket up to 90°C can be obtained. It is possible to produce intensive blending, to distribute liquids in solids, to disperse liquids under vacuum, to dry materials under vacuum and to carry out chemical reactions. An unusual application is the neutralising of static charge in materials by dispersing in the blend a suitable liquid which can be removed subsequently by vacuum drying. It is also possible to dry materials to a fraction of a per cent of moisture when the drying medium is hot gas.

A feature of the design is the previously-mentioned dispersion bar, which spins when the vessel is in motion and is equipped with precision-mounted dispersion discs which ensure a uniform distribution of liquid in the solid charge.

A further noteworthy feature is provided by the design. Thus when the unit is used for drying filter cake material of fine particle size, of the kind which tends to form progressively smaller balls during drying, a stage is reached where an insulating layer encloses the balls and prevents further drying. To meet this situation a separately-operated agitator bar is provided which can be set in motion to fracture the balls and thereby permit complete drying down to a fine powder. **The Patterson-Kelley Co. Inc., East Stroudsburg, Pennsylvania, U.S.A.**

BCE 8444 for further information

Design and Installation of Small Gas-fired Incinerators

A new report of the Industrial Gas Development Committee deals with small incinerators for disposing of waste. The incinerator itself is simply a gas burner fited in a fire box with bars on which the material rests while being dried and ignited. Because of unpleasant gaseous products, means must be provided of venting these to atmosphere, either by natural or mechanical draught. This will still apply even when incinerators designed to destroy refuse with smokeless combustion, now being developed, become available. Choice of method must be governed by a number of factors. A correctly designed mechanical extraction system will, of course, minimise the risk of unpleasant combustion products finding their way into the building due to downdraught. Consequently the system should always be recommended where doubt may exist as to the adequacy of natural draught.

The report covers possible ways of dealing with the problem and deals with regulations and requirements. It gives a design method with the necesary equations and nomograms for rapid solution together with recommendations on sizing of flues.

Report No. 718/59 of the Industrial Gas Development Committee of the Gas Council.

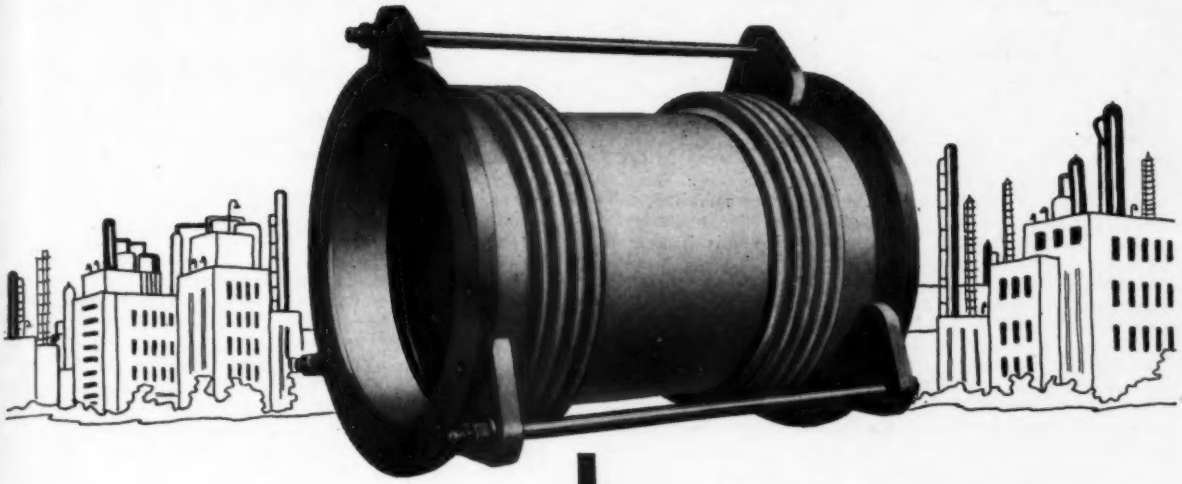
BCE 8445 for further information

Heating Elements

There are many heating requirements in industrial engineering which call for the evenly distributed application of relatively low temperatures over large areas. When used for this purpose, high-temperature linear elements are said to suffer from certain inherent short-comings. Mhoglas non-metallic area heating element is, say the manufacturers, the successful outcome of seven years of intensive research devoted specifically to the discovery of a satisfactory method of heating large areas

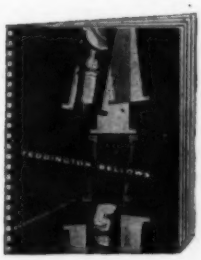
evenly at temperatures ranging from a few degrees to 250°C or so, using potentials from 2 or 3 volts up to normal mains voltage. It was clear from the outset that if perfectly even distribution of heat were to be assured this would demand the use of a heating element equal in size to the area of the surface to be heated. It was clear, too, that metal elements could not

The use of **BELLOWS** in Chemical Engineering



Wherever pipes operate under conditions of temperature and pressure, expansion joints may be required. The bellows type expansion joint has in the past few years become standard equipment, being now recognised as extremely efficient. Teddington engineers have played a leading part in the introduction of stainless steel bellows expansion joints to the chemical industry and can be relied on to co-operate fully with design and plant engineers who are confronted with pipe problems.

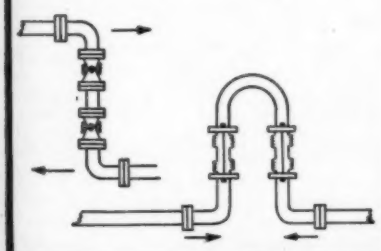
SEND FOR HANDBOOK No. M 102



Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

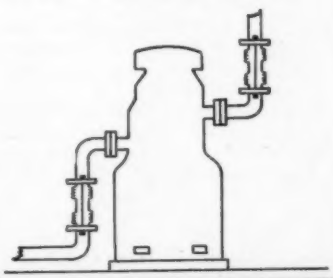
IN PIPELINES

Restrained double units operate in shear to accommodate large movements with negligible anchor loads. Two restrained double units can be used to make a very flexible, small dimension pipe loop for large expansion.



ISOLATING PUMP MOVEMENT

In the pipework connected to a pump, restrained double units fitted at right-angles to the plane of vibration will operate in shear to accommodate the movement and protect the pipework.



SEALING VALVE STEMS

Bellows units provide an absolutely leak-proof seal on valve stems.

Made under licence from the Solar Aircraft Co., California, U.S.A.

TEDDINGTON

STAINLESS STEEL FLEXIBLE BELLOWS EXPANSION JOINTS

TEDDINGTON AIRCRAFT CONTROLS LTD (*Industrial Bellows Division*) Ammanford, Carmarthenshire. Tel: Ammanford 2255

M102

PLANT EQUIPMENT NEWS

be used—in the form of fine-woven mesh or foil—their resistivity being far too low for the purpose. The answer to the requirement was clearly graphite. The most suitable base for the graphite proved to be a glass fibre fabric, the extremely fine and continuous mono-filaments of which (approximately 120 to each strand of the fibre) receive an exceedingly thin and perfectly even coating of graphite of virtually colloidal fineness. The resultant Mhoglas element thus consists of many thousands of microscopically fine conductors in parallel, and when current is passed through the element it therefore heats up evenly over the whole of its area. The glass fabric, having received its controlled deposit of graphite, is then bonded with a suitable heat-resistant resin to "lock" and protect the graphite during subsequent handling processes, the finished element being thin, light in weight, tough and flexible. The new non-metallic area element can be manufactured to give any desired degree of resistance from 4 to 150 Ω per square, can be run at temperatures up to 100°C in the normal range (and 250°C in the high-temperature range), can be loaded up to 150 W per sq. ft—and much higher loadings where the rate of heat dissipation permits—and can be produced in units of any size and shape to meet specialised requirements. **Hunting Mhoglas Ltd., Craddock Road, Luton, Beds.**

BCE 8446 for further information

Infinitely Variable Speed Reduction Unit

A new type of variable speed transmission device has no gears, belts or fluid drive. It is known as the "CONTORQ" and transmits constant torque over its entire speed range. These properties are produced by the following mechanism:

Two single lobe cams are secured to the input shaft, the lobes being fixed at 180° to each other. Rotation of the cams imparts an oscillating movement to two levers which, in turn, oscillate two further levers, each of which is in contact with a roller type freewheel mechanism attached to the output shaft. Adjustment of the control knob moves a roller which is interposed between the first and second sets of levers, thereby varying the angular movement of the latter from zero to a maximum. The angular arrangement of the cam lobes imparts a continuous motion to the output shaft; as one freewheel is driving, the other is returning to its starting position. The cams are designed to give constant angular velocity and overlap to eliminate loss of movement at the change from one freewheel to the other.

The standard unit operates from a constant input speed of 450 rpm, which gives an infinitely variable speed range on the output shaft of 0-50 rpm, but other arrangements are also possible. Speed changes are made by the turn of a graduated dial, and the changes may be effected whilst the unit is in operation or at rest. Remote control by servo or push buttons can be provided if required. The standard unit has a maximum output torque of 2500 in. lb, but a large one of 13,000 in. lb has now been designed. **Fairbairn, Lawson, Combe, Barbour Ltd., Leeds, 1.**

BCE 8447 for further information

Automatic Beryllium Monitor

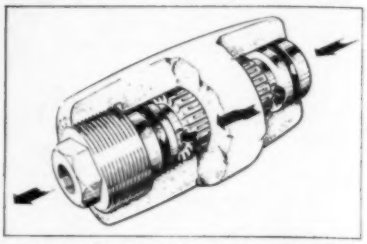
A new analytical instrument for beryllium based on photo-electric measurement of spectrogram lines is claimed to be the most accurate in the world. The results produced are said to be quantitative over the range 1-75 millionths of a gram per cubic metre, unaffected by the size of particle and produced in sixty seconds. The air sample is drawn through a triggered alternating current arc and the ultra-violet radiation resolved by a spectrograph of high dispersive power. The intensity of the beryllium doublet at 3130Å is measured photo-electrically and the ratio of the intensity of this doublet to the intensity of the adjacent background is recorded on a chart.

The apparatus is fully automatic. It operates on a predetermined cycle in which it is first calibrated, and then records a series of results at one-minute intervals. The air flow rate is 40 litres/min. In a recent demonstration the monitor was shown set on a 25-minute cycle involving 5 calibration runs (blanks and standard) and 20 sample determinations. Power consumption is 2.5 kW. The beryllium monitor—a redesign of an earlier model—was designed and developed by Messrs. M. S. W. Webb, R. J. Webb and P. C. Wild of the United Kingdom Atomic Energy Authority's Woolwich Outstation and is licensed by the Authority. It is manufactured by **Winston Electronics Ltd., Shepperton, Middlesex.**

BCE 8448 for further information

Adjustable Filter for Fluids and Gases

This filter has been developed to meet the demand arising from the trend towards smaller particle sizes. It presents an infinitely variable filtration gap which can be adjusted to meet precise requirements while the filter is in its installed position. The element of the filter can be completely exposed for cleaning without breaking the pipeline.



A graduated scale on the end of the filter housing indicates the various settings which may be selected in increments of one micron. The advent of an adjustable filter marks a radical departure from conventional practice and offers a realistic and accurate means of achieving 100% cut-off with any particle size, since the filtration gap can be diminished at will to meet changing conditions.

Standard models cover ranges of 6 and 11 microns and there are three models for each pipe size. For example, the ¼-in. model comes in three variants catering for the ranges (i) 0 to 5 microns; (ii) 5 to 15 microns; (iii) 15 to 25 microns. **I.V. Pressure Controllers Ltd., Feltham, Middlesex.**

BCE 8449 for further information

Tests of Electronic Flame Failure Devices

Devices manufactured by Radiovisor Parent Ltd. for dealing with flame failure have been tested by the Gas Board Laboratories at Watson House. Type FR 56/SS utilises the principle of flame conduction as the means of detection, and incorporates a safe start relay in its design. Type FR 56/SC is based on the same principle, but is combined with an automatic programme timer giving a full purging and lighting-up sequence by the operation of a single press-button.

Both models comply with existing requirements as laid down in I.G.D.C. Report No. 611/56, U 96, entitled "Flame Protection Practice (1956), a Review of the Present Position", which was published in full in **B.C.E.**, Dec 1958 and Jan 1959. The present report notes that

THE ACTIVITIES OF THE

PRODORITE

ORGANISATION are concentrated on all problems concerning chemical corrosion and mechanical wear and tear:—

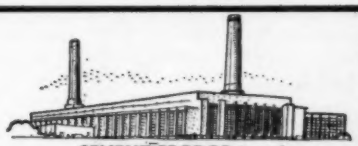
1 CONTRACT WORK

concerned with chemical engineering; acid proof constructions and industrial finishes; floor laying; complete plant design, installation and maintenance; effluent disposal and drainage schemes, carried out by our own personnel using Prodorite products.

Extensive sub-contracts in C.E.A. Power Stations

2 CHEMICAL RESISTING CEMENTS

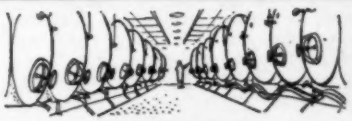
and compounds for all types of industrial application. These cements fall into two basic categories: silicate based and resin based; the two combined ensuring the availability of a suitable cement to fill every anti-corrosive need.



CEMENT PRODOR *is used for these power station chimneys*

3 PROTECTIVE COATINGS and LININGS

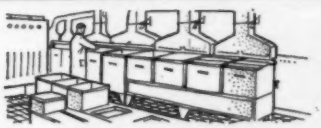
to storage and transport tanks and pipelines; for industrial processes; and linings to vessels for foodstuffs, beverages and aviation fuels. Available for bonding or spraying on site in a variety of forms.



PRODOR-GLAS *lined cold room tanks*

4 PLASTICS FABRICATIONS and RESIN/GLASS LAMINATES

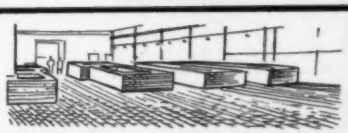
Rigid P.V.C.; plasticised P.V.C.; polythene in welded sheet form for fume ducting, tank linings, fans etc; for chemical, plating, pickling and allied industries. Complete range of ORGLAS laminates having highest possible chemical and temperature resistance. Wide industrial applications, including the food industry.



P.V.C. *fabrication scheme for fume extraction*

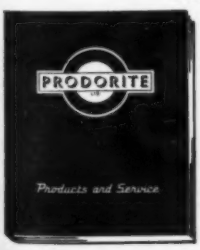
5 INDUSTRIAL WALL and FLOOR FINISHES

including acid resisting and heavy duty types in the form of paviors, tiles, flags, and insitu, with suitable additives. Also decorative wall and floor treatments for use in flats, hotels, public buildings, etc.



Corrosion resisting floors and walls in Acid Pickling shop

The products and services of the Prodorite Organisation extend from the manufacture and supply of materials to complete constructions carried out by the Contracting Department to customers' requirements. Prodorite products give complete protection from atmospheric conditions, chemical corrosion and mechanical wear and tear of any sort.



SEND FOR YOUR FREE COPY OF THE PRODORITE BOOKLET

This stiff-cover publication contains 25 pages of invaluable information about the products and services of the Prodorite Organisation. It includes photographs of actual installation and details of the Prodorite research, development and consultation services. Technical information about individual products is also available in leaflet form. Please quote publication reference number: P 103

Write to: **PRODORITE LIMITED** (Chemical Engineers and Consulting Contractors) **EAGLE WORKS, WEDNESBURY, STAFFS.,** or Telephone Wednesbury 1821 (10 lines).

PLANT EQUIPMENT NEWS

model FR 56 does not incorporate a safe start feature in its design, and fails to satisfy the requirements of the Industrial Gas Development Committee. The FR 56/SS model does, however, include these additional safeguards: therefore, care should be taken to quote the specific number when ordering this model. The report gives descriptions of the electronic unit, flame electrode, start unit and of the method of installation. Tests applied included flame failure, false signal at probe and shorting between probe and earth. Details are available in the report of the Industrial Gas Development Committee of the Gas Council. **Radiovisor Ltd., High Path, London, S.W.19.**

BCE 8450 for further information

An Exhibition of Special Instruments

At an exceptionally large single-company exhibition, held recently at Birbeck College, Griffin & George had on view a number of instruments, of which the following were particularly noteworthy.

Humidity Control Instruments

The range of Ersec equipment manufactured by Wallac Oy of Finland included humidity control instruments suitable for remote reading, local measurements, automatic control and recording of humidity of air, propane, coal gas and the like. The measuring principle is based on the stable physical properties of lithium chloride salt. It reads directly in dew point, is rapid in response and requires no critical adjustments. The instrument will operate over a temperature range of −30°C to +100°C and an absolute humidity of 0.1-150 mm Hg. The accuracy is ±1°C dewpoint, corresponding to ±2% relative humidity at 60% and 20°C.

Gas Density Ratio Monitor

Continuous monitoring of any two-component gaseous mixture may be carried out by means of an instrument based on comparison gas densities. It was originally devised by A. J. P. Martin and A. T. James and has been developed by Monsanto Chemicals. Examples of mixtures that can be monitored by this means are organic vapours in air or oxygen, oxygen in nitrogen and water vapour in any permanent gas. Extended field trials have been conducted at a phthalic anhydride plant.

The full-scale sensitivity of the instrument is approximately a density differential of 0.05 g/litre, and is considered to be adequate for the majority of possible applications, although some increase in sensitivity may be obtained by slight modification to the gas-density balance. The output signal from the gas-density balance is fed to a recording, electronic potentiometer which is housed in a separate modular unit.

Absorption Chromatograph

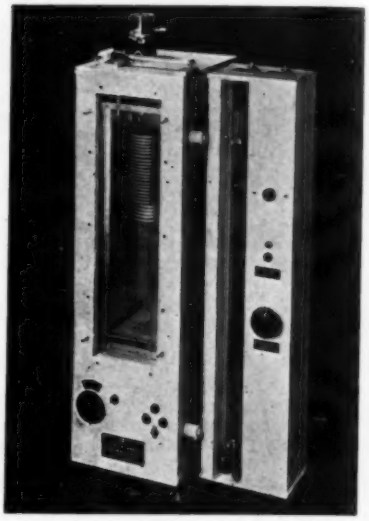
Carbon dioxide is used as the carrier gas in a new absorption chromatograph which can be used for the quantitative analysis of petroleum gases which contain hydrogen and hydrocarbons up to C_4 (excluding the acetylenes). Hydrocarbons in the C_5 range may also be determined in certain circumstances. The separations may be based on either adsorption (gas-solid) or partition (gas-liquid) chromatography. The range of gas mixtures includes nitrogen, oxygen, carbon monoxide, hydrogen, methane, ethane, propane, 2-methylpropane, n-butane, 2-methylbutane (small concentrations of up to 1%), ethene, propene, 2-methylpropene, 1-butene, cis-2-butene, trans-2-butene and 1,3-butadiene. The quantitative accuracy of the method is within the limits ±0.25%, and the lower level of component detection is of the order of 1%.

Dielectric Monitor

If changes in dielectric constant are used as the principle of detection for analysis, it is claimed that the instrument based on it is insensitive to changes in rate of flow, robust, has a long linear range, high resolution and high speed of response. In conjunction with suitable chromatographic columns, this detector has been widely applied. In addition, use as a continuous process monitor is being investigated. The detector body is a cylindrical brass block in which two parallel chambers have been drilled. This detector is not affected by changes in carrier-gas flow in the range 0-5 litres per minute and in the case of nitrogen to pressure changes of up to 10 cm Hg. Long-term drift is negligible. The intrinsic response time of the apparatus (indicating meter and/or recorder excepted) is 0.5 millisecond. Sensitivity at a given concentration is proportional at a particular temperature to the dielectric constant of the substance detected minus one. Acetone may be detected at a concentration of 2 micrograms per litre in nitrogen or diethyl ether at 8 micrograms per litre.

Flame-ionisation Unit

For the detection of the constituents of the stream coming from a chromatographic column, a useful method is selective thermal ionisation, the constituents being burnt in a flame of hydrogen. A very high signal-to-noise ratio is obtained, and background signal is reduced almost to zero. The degree of ionisation found experimentally is usually much greater than that expected from calculation. The flame-ionisation detector can analyse gas samples of volumes as low as 0.01 ml.



Even with samples of fairly large volume, as, for example, 1.0 ml, a sample of ethane and ethylene (in the volume ratio 95 to 5) would be satisfactorily resolved on a 15-ft column of 25% (w/w) liquid paraffin on Celite 545 at 20°C, where the column efficiency is equivalent to 300 theoretical plates.

Temperature-sensing Elements and Thermo-anemometers

A number of the Wallac Oy instruments incorporate temperature-sensing elements. Those intended purely as resistance thermometers include the following: For nearly flat surfaces a unit with self-aligning contact surface of silicone rubber suitable for temperatures up to 180°C; for curved surfaces a very sensitive probe with soft and elastic, self-aligning contact surface of rubber for a maximum temperature of 120°C; for liquids and universal use, a temperature-sensitive nickel resistor sealed in a stainless-steel capsule for a maximum temperature of 120°C; for air and gases a very fast responding air and gas temperature probe, equipped with radiation shield—time constant less than 0.5 sec—usable to +150°C; for semi-fluid materials a needle type, capable of measuring a maximum temperature of +160°C; and for revolving surfaces an element which gives the accurate surface temperature up to 200°C without direct contact between the detector and the rotating surface. **Griffin & George Ltd., Ealing Road, Alperton, Wembley, Middlesex.**

BCE 8451 for further information

BCE 8382 for further information

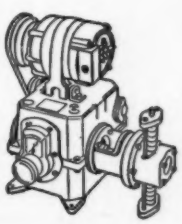
A superb small capacity metering pump

The Metrivar Type "K"

This is a small capacity variable stroke pump with a maximum length of stroke of ½". The pump is driven by a totally enclosed, vertical spindle motor and a selection of pump heads is available, in ebonite and glass, polythene and glass and in stainless steel. The utmost care is taken in manufacture and assembly of these small pumps and each unit is subjected to strict inspection at each stage of production and testing is under full load conditions.

There is no substitute for experience in recommending metering pumps for specific problems.

Metering Pumps Limited

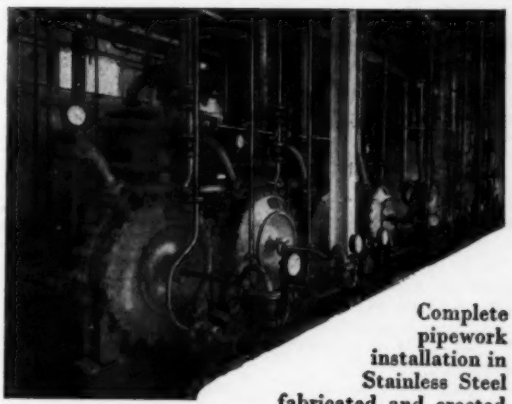


Metering Pumps Limited, 21, The Mall, Ealing, London, W.5
Telephone: EALing 6264 (PBX)

BCE 8383 for further information

Stainless Steel . . .

tanks, coils and pipework by *Jenkinsons*



Complete pipework installation in Stainless Steel fabricated and erected on site by JENKINSONS.

Also fabricated and erected on site by JENKINSONS, Stainless Steel ducting 9 ins and 18 ins dia. with special smooth finish both internally, to minimise friction losses, and externally, to improve corrosion resistance.

W. G. JENKINSON LTD.
ARUNDEL STREET; SHEFFIELD 1.
Phone 27438/9

World of Chemical Engineering

Photogrammetry to Replace Models

New industrial applications of photogrammetry, the technique of three-dimensional measurement from stereoscopic photographs which is usually associated with map-making from aerial photography, was demonstrated at the Ninth International Congress of Photogrammetry held in London at the Senate House, University of London, from September 5 to 16, 1960.

Cameras and plotting equipment are being developed as a design tool in preparing layout drawings of complex installations—in particular, for chemical plant and oil installations involving intricate pipework. In recent years it has been the practice to work out the layout of such installations by means of scale models, from which the working drawings have then to be prepared. Using stereoscopic photography and plotting machines to produce plans and elevations, much of the time and cost involved in measuring up the model and making the drawings can be eliminated.

The same technique is arousing the interest of the automobile industry for preparing the working drawings for the bodywork of motor-cars, the lines of which are usually evolved on a three-dimensional styling model.

(Address of Congress Director: 18 Cavendish Square, London, W.1. Firm developing the photogrammetric equipment: Leland Instruments Ltd.)

New Plants for Ethylene and Polypropylene

The manufacture of ethylene and related compounds continues to expand and, in addition to the third British Hydrocarbon Chemicals ethylene plant at Grangemouth which went into production recently, a number of other developments of a similar kind, actual and projected, have been reported. For example, polyethylene to the extent of 110,000,000 lb. per annum will be the output of a new Union Carbide plant to be erected on the southern coast of Puerto Rico. Together with the existing chemical manufacturing units already in operation at the site of the plant, this will represent the largest industrial investment in Puerto Rico.

The plant itself will have the greatest capacity for polyethylene of any in the world.

Other polyethylene manufacturing facilities are likely to be realised at Kawasaki, Japan, where Asahi-Dow Ltd. propose to erect a plant based upon the A.G. für Olefinpolymerisation process. The principal licensor of this process, The Scientific Design Co. Inc., of New York, have granted the licence to the Japanese company for the exclusive use of this process.

The manufacture of three new propylene derivatives was announced recently by Solvay. The three products; allyl chloride, allyl alcohol and glycerol epichlorhydrin will be made in a new plant soon to be in operation at Travaux in France. At present the facilities at Travaux are concerned with caustic soda, various halogen derivatives including vinyl chloride and polymers.

The manufacture of the three chemicals named marks the first stage of a programme of allyl derivatives manufacture. Production of synthetic glycerine is also included in the current plans.

In Germany, Chemische Werke Hüls A.G. report that the bottleneck in ethylene supplies which had persisted for some time was recently removed through the recent placing into service of an additional ethylene separator. Subsequently, a new ethylene oxidation plant was started up and the manufacture of ethylene oxide by the chlorhydrin process was discontinued.

The styrene plant at Hüls has also been extended and installations for the manufacture of polyethylene by the low-pressure method and of phthalic anhydride also came into service.

Research work carried out during the past year has been devoted to methods of producing new materials from cyclododecatriene. Intensive work has been devoted also in the fields of polyolefins and polydiolefines and since the polyethylene plant came into operation considerable use has been made of the company's development work on polyethylene qualities for all kinds of applications. Polypropylene is also now being manufactured in pilot-plant quantities.

New Chemical Plant Design Facilities

Polyethylene manufacture from the design angle is now occupying a section of the design staff of George Wimpey & Co. Ltd., who have been charged with the design and procurement of a £4A million polyethylene plant for Australia; this is in addition to a number of other projects, including a chemical plant to be erected in Antwerp and home contracts, embracing chemical, mechanical, electrical and instrument engineering to be undertaken for various petroleum and chemical companies at Carrington, Grangemouth, and the Isle of Grain.

Most of the design work will be carried out at the new Wimpey premises, known as Flyover House at Chiswick, where the floor space exceede 100,000 sq. ft.

I.C.I. and Polypropylene Fibre

I.C.I. have negotiated a patent licence agreement with Montecatini of Milan for the manufacture of polypropylene fibre. This follows on the previous licensing arrangement with Montecatini whereby I.C.I. are to produce polypropylene itself to the extent of 10,000 tons a year from their plant which will shortly be in operation at Wilton.

Oxygen Plants for Steelworks

Despite strong competition from firms in Germany and France, as well as other U.K. firms, Air Products (Great Britain) Ltd. have been commissioned to construct a 380 tpd oxygen plant at the O. Singaglia steel works, Cornigliano, Genoa, Italy. This is the first oxygen plant to be built for an Italian steel works and it will consist of two units with storage capacity of 560 tons of liquid oxygen and 420,000 cu. ft of high pressure oxygen. In addition to the oxygen output, which will be mainly in gaseous form, nitrogen of 99.8% purity will also be produced and will be used for annealing purposes. The gas-separation plants are of the "split cycle" type, a feature providing for the economic production of a useful proportion of liquid oxygen in addition to the main output of gaseous oxygen.

In conjunction with The Butterley Co., Air Products have also finished the erection of a 200 tpd oxygen plant at Stewarts & Lloyds, Corby. This is the first tonnage oxygen plant to be owned and operated by a steel company in Britain. The plant produces gaseous oxygen at 350 psig. 99.5% purity and gas storage is provided for 370,000 cu. ft of oxygen.

Contracts

Plants for the production of acetic acid are the subject of two contracts awarded to the Stockholm firm AB Chematur, each being worth two million Swedish crowns. One plant is for Andhra Sugars Ltd., Madras, and the other for Indian Organic Chemicals, Bombay; each will have an output of 10 tons of acetic acid per twenty-four hours.

Buell Ltd., a subsidiary of Edgar Allen & Co. Ltd., are to supply The Lancashire Steel Manufacturing Co. with a drying plant complete with high-efficiency dust collectors, all of Buell design, together with the ancillary equipment. The duty is to dry 225 t.p.h. of wet Northants ore from an initial average moisture content not exceeding 18% to a final moisture content of 12%. The value of this contract is in excess of £200,000.

Another contract for drying equipment requires the erection of three vertical turbo driers, also of Buell design. These driers, each of which will have an output of 9½ t.p.h. of china clay, are to be installed at different sites in Cornwall and the first is to be in operation by March of next year. The total value of the order is approximately £100,000.

In addition to these, orders of smaller value have been received for dust collection equipment for the discharge end of a sinter plant.

BCE 8384 for further information

MIKRO-Products

SPAN THE GLOBE

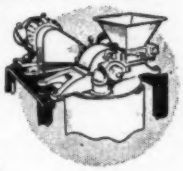
PROCESSING SYSTEMS

GRINDING CONVEYING COLLECTING

Mikro-D *Equipment for grinding & blending to fine quality powders and dusts*

THE MIKRO-PULVERIZER

A high-speed mechanical pulverizer offering a wide range of particle sizing (10-300 mesh). Safe and economical for both wet and dry grinding. Available in six size capacities from 10-10,000 lb per hour.



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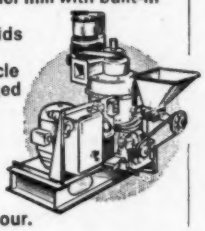

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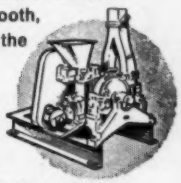

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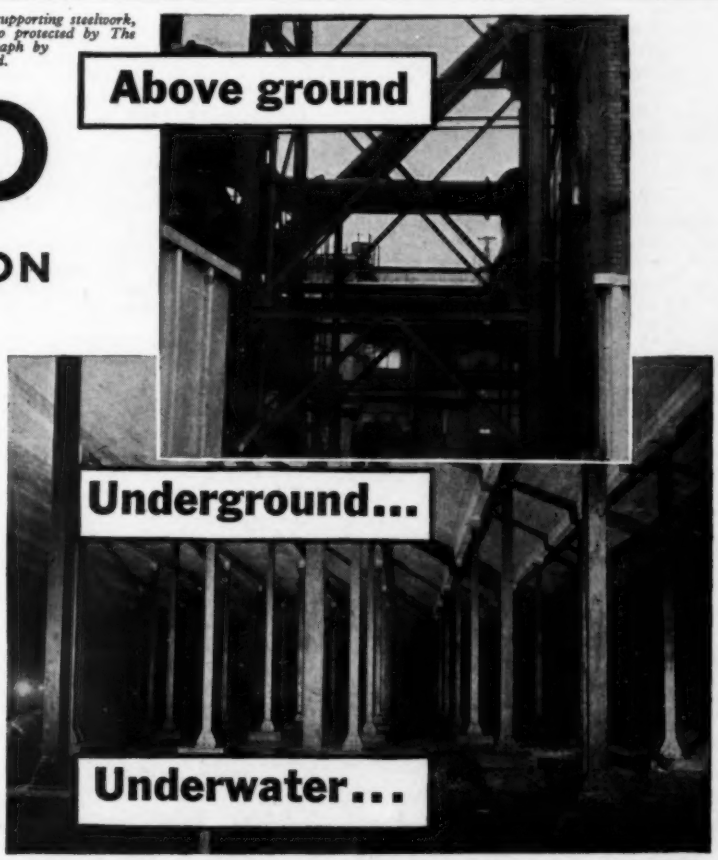

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